GRBs: Internal Shock Scenario

Frédéric Daigne (Institut d'Astrophysique de Paris)

avec Robert Mochkovitch et

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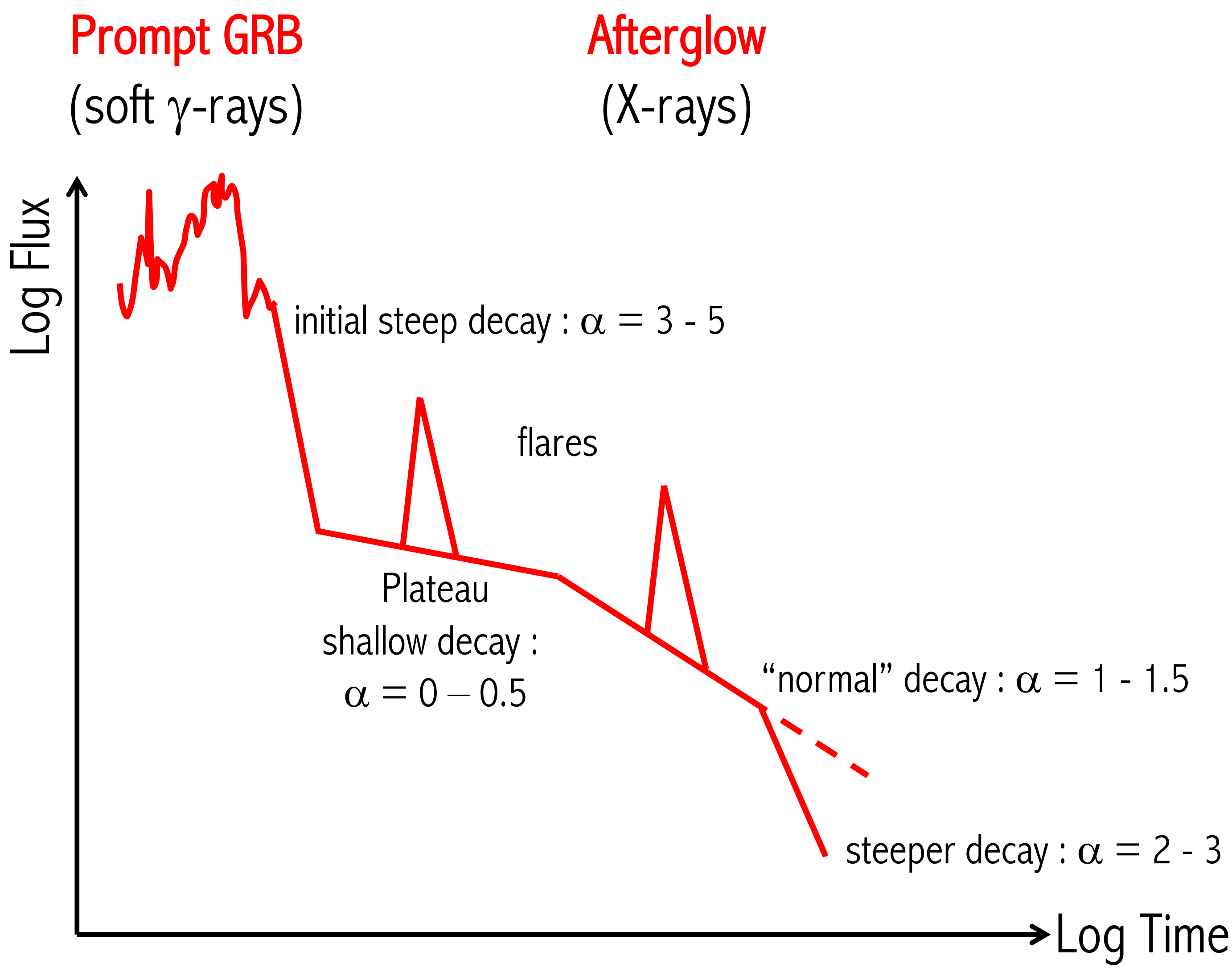
Sylvain Guiriec, Manal Yassine, Maria-Grazia Bernardini, Frédéric Piron

Simulating the evolution and emission of relativistic outflows – Meudon, 28-29 Novembre, 2019

GRBs: observed emission

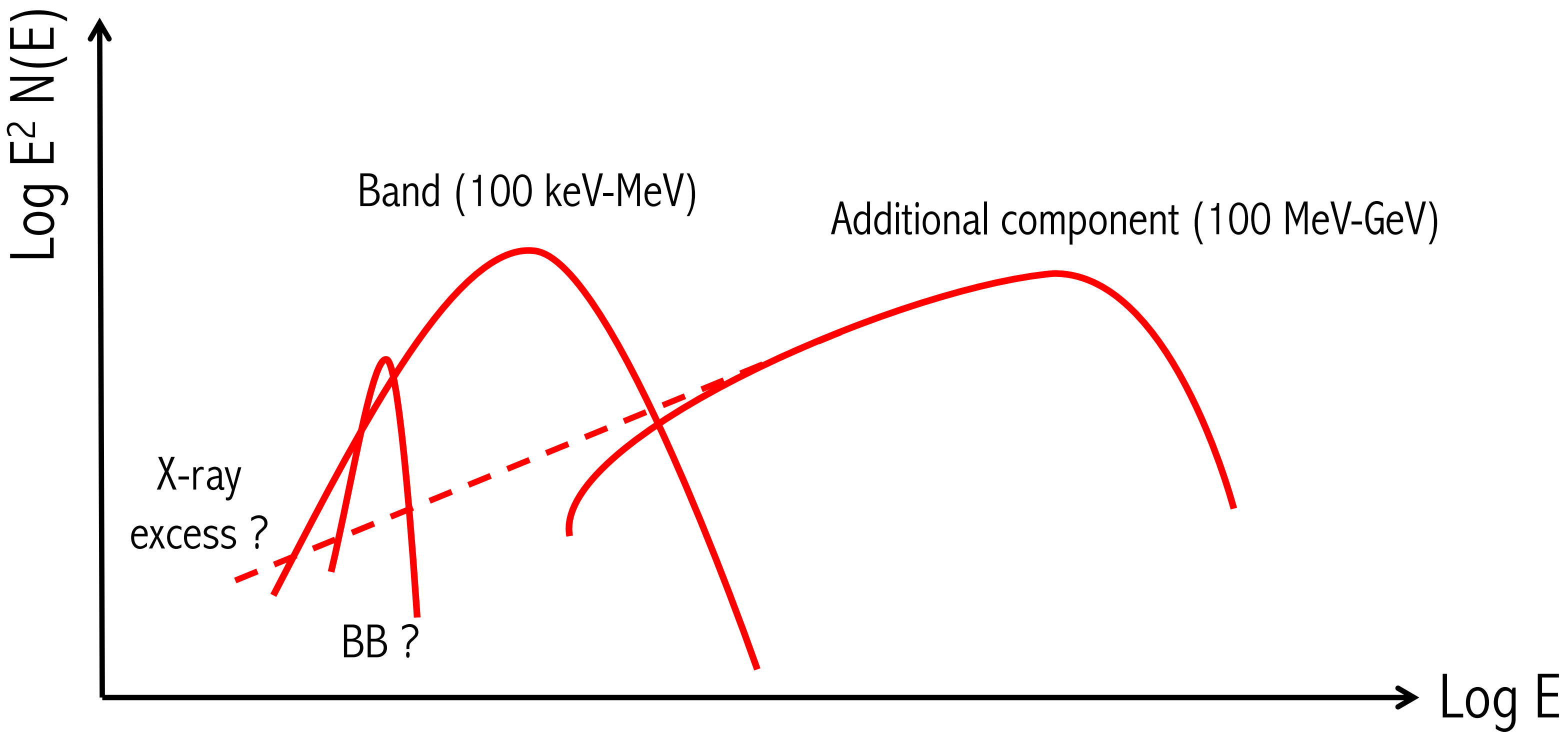
Observed emission



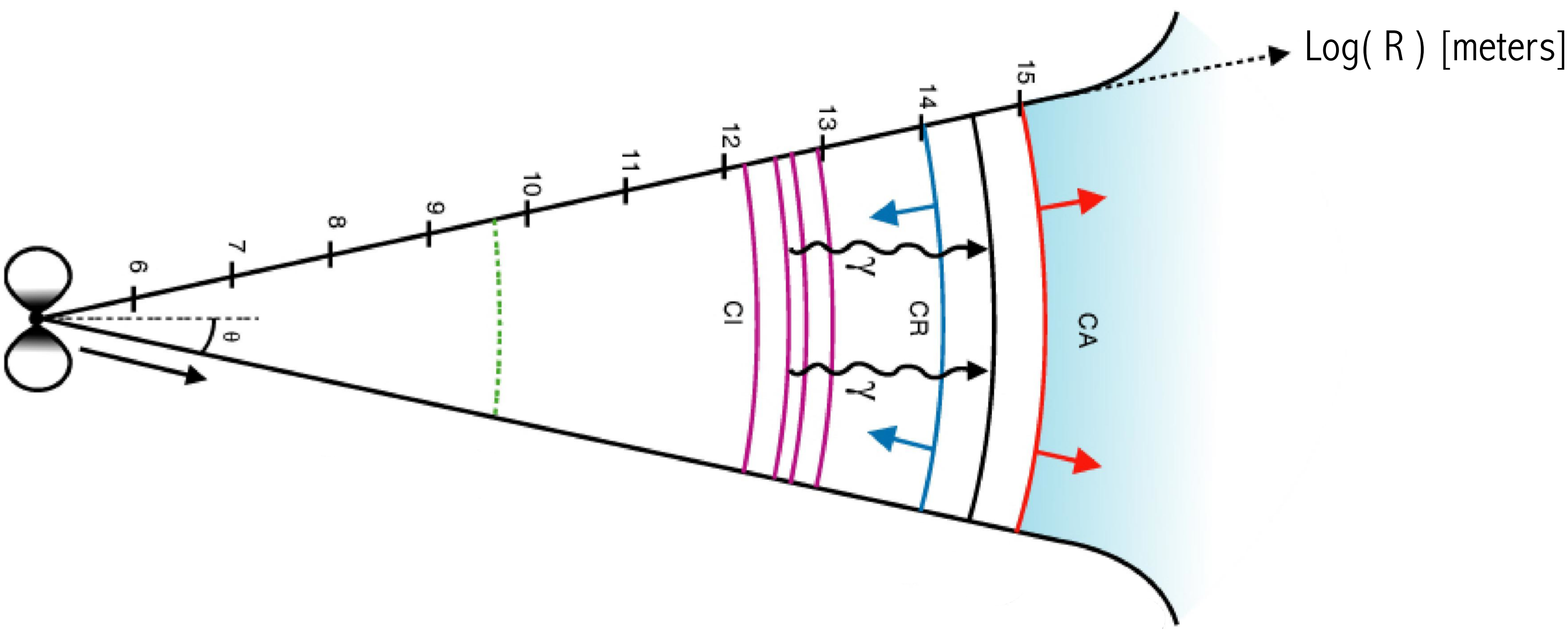
Also: prompt optical, GeV

Also: optical, radio afterglow long-lasting Fermi/LAT emission

Observed prompt γ-ray spectrum



GRB physics

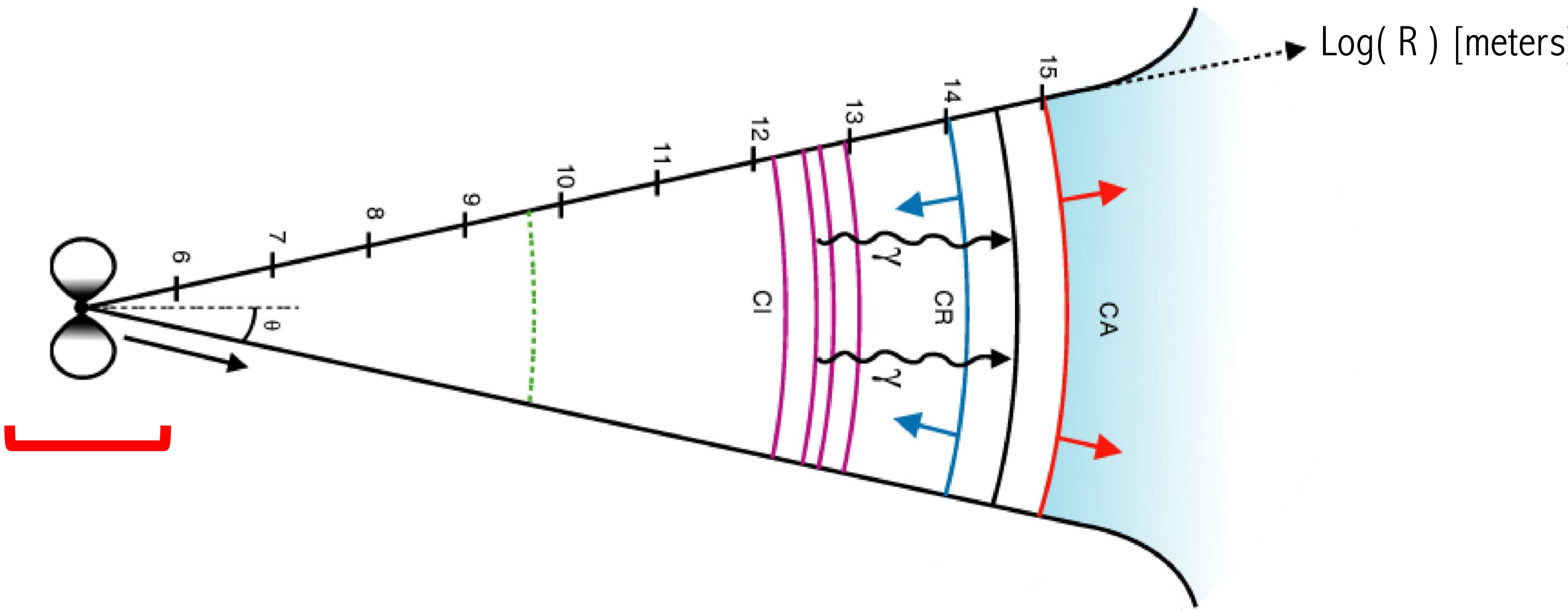


GRB physics

- Cosmological distance: huge radiated energy ($E_{iso,\gamma} \sim 10^{50}$-$10^{55}$ erg)
- Variability + energetics: violent formation of a stellar mass BH/magnetar

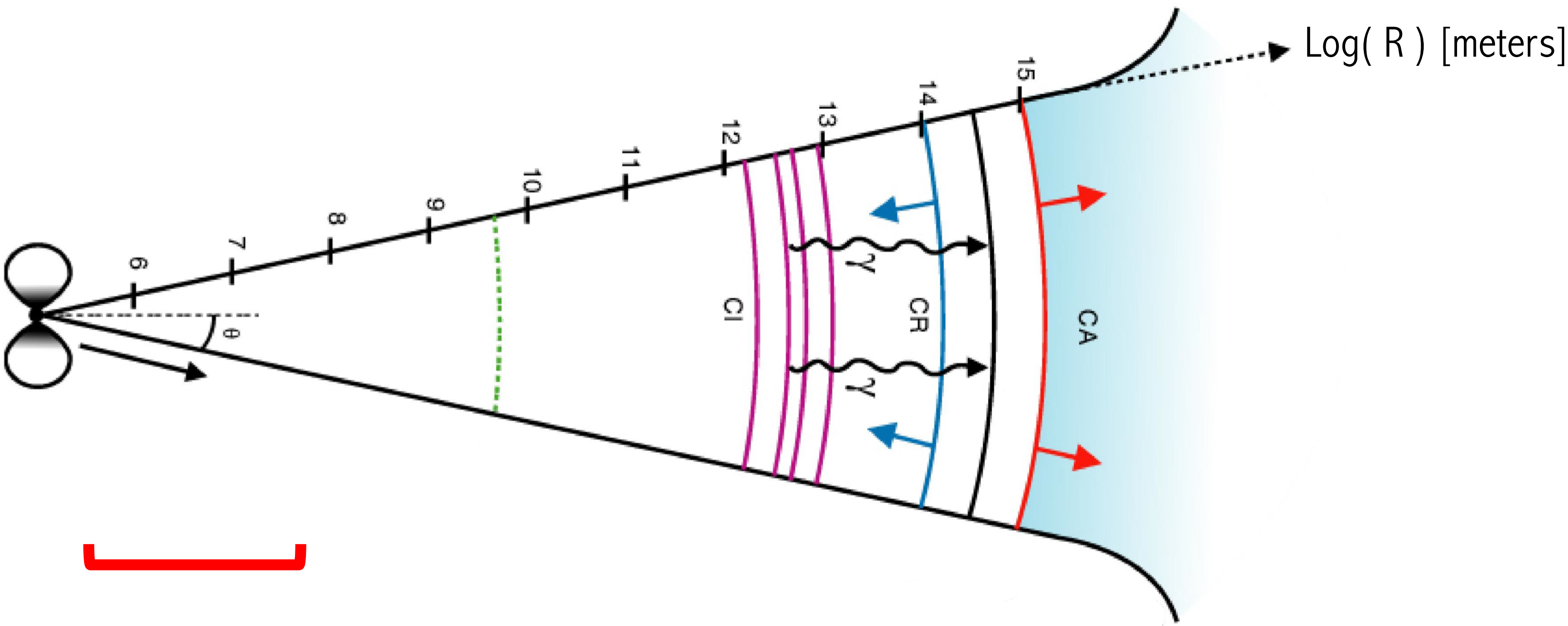
Long GRBs: collapse of a massive star

Short GRBs: NS+NS(/BH ?)merger(?) [GRB170817/GW170817A]



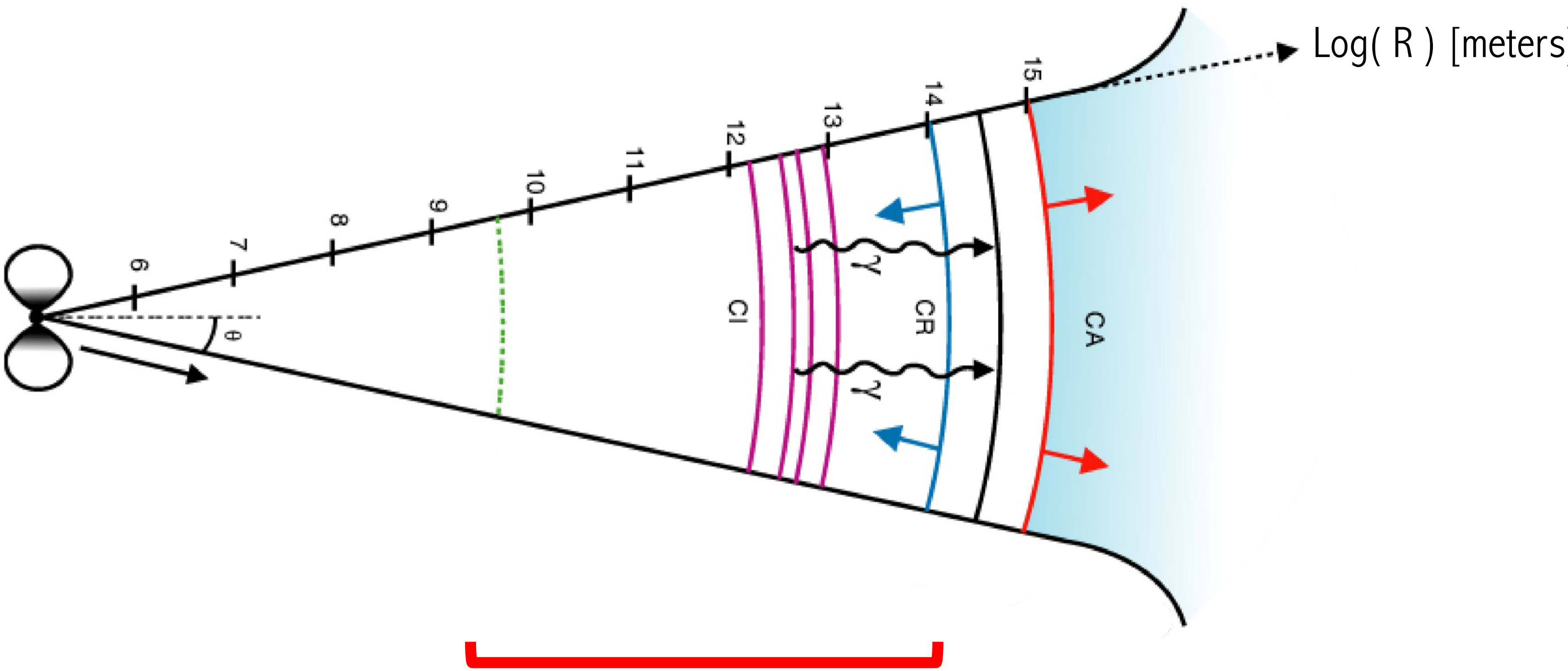
GRB physics

- Variability + energetics + gamma-ray spectrum: relativistic ejection



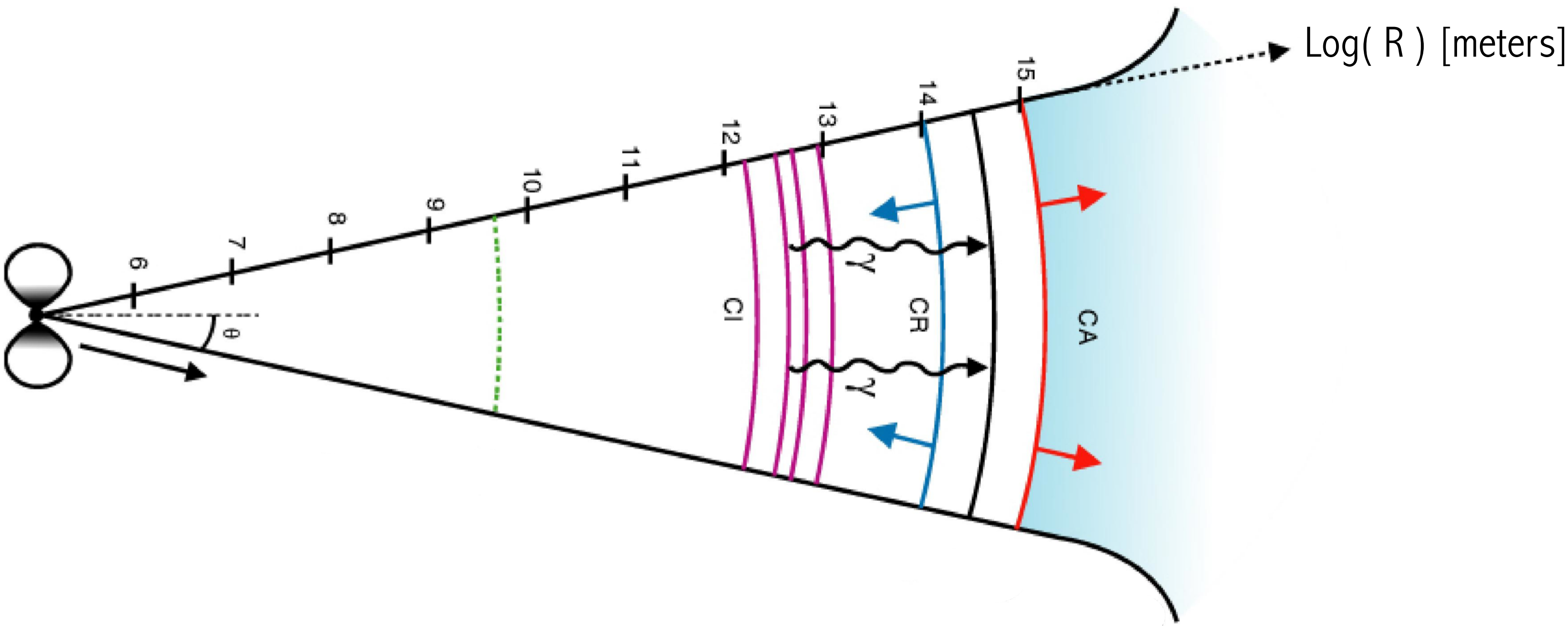
GRB physics

- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt keV-MeV emission: internal origin in the ejecta



GRB physics

- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt keV-MeV emission: internal origin in the ejecta
- Afterglow: deceleration by ambient medium

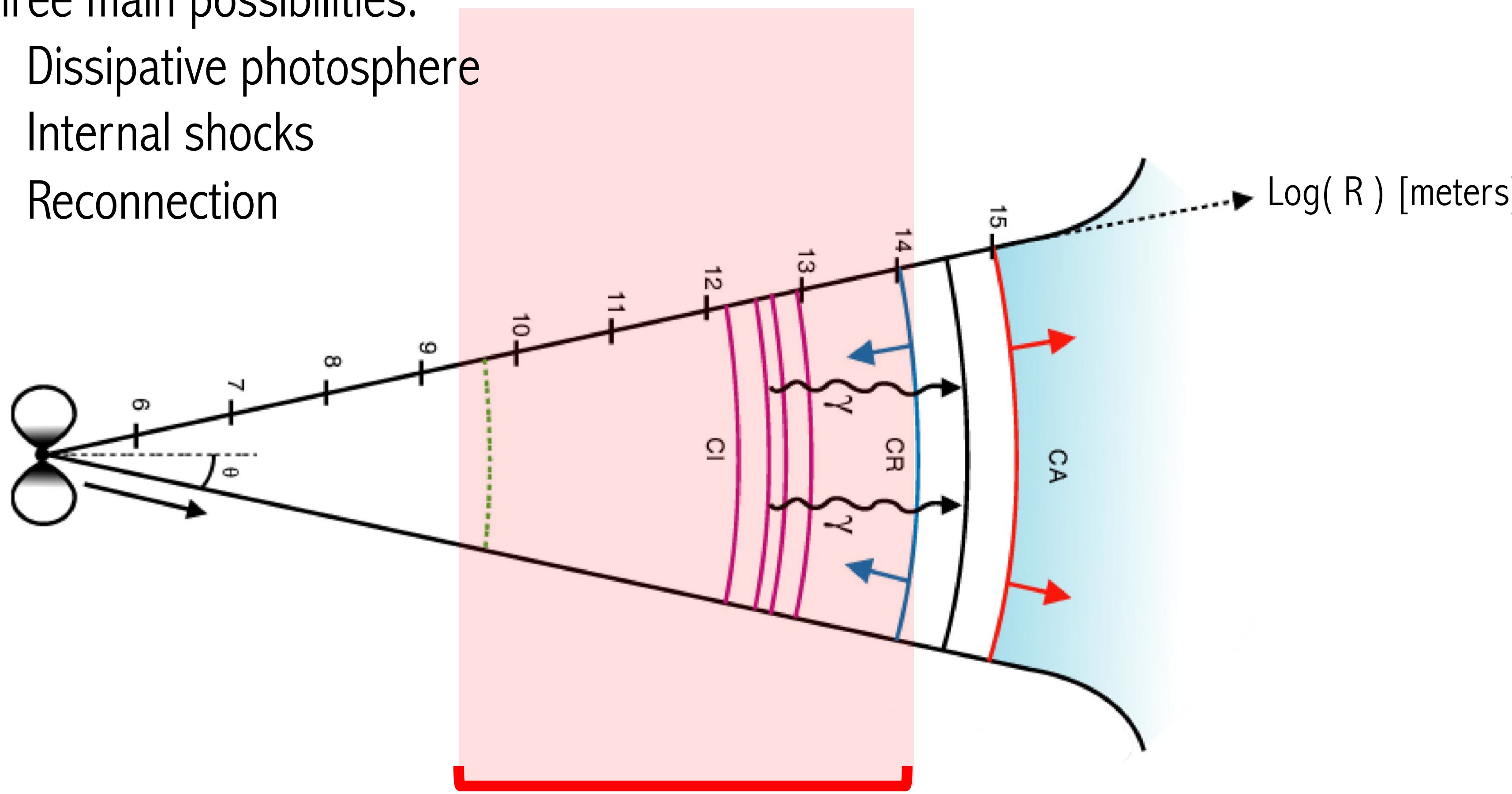


GRB physics

- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt keV-MeV emission: internal origin in the ejecta

Three main possibilities:

- Dissipative photosphere
- Internal shocks
- Reconnection



GRB physics

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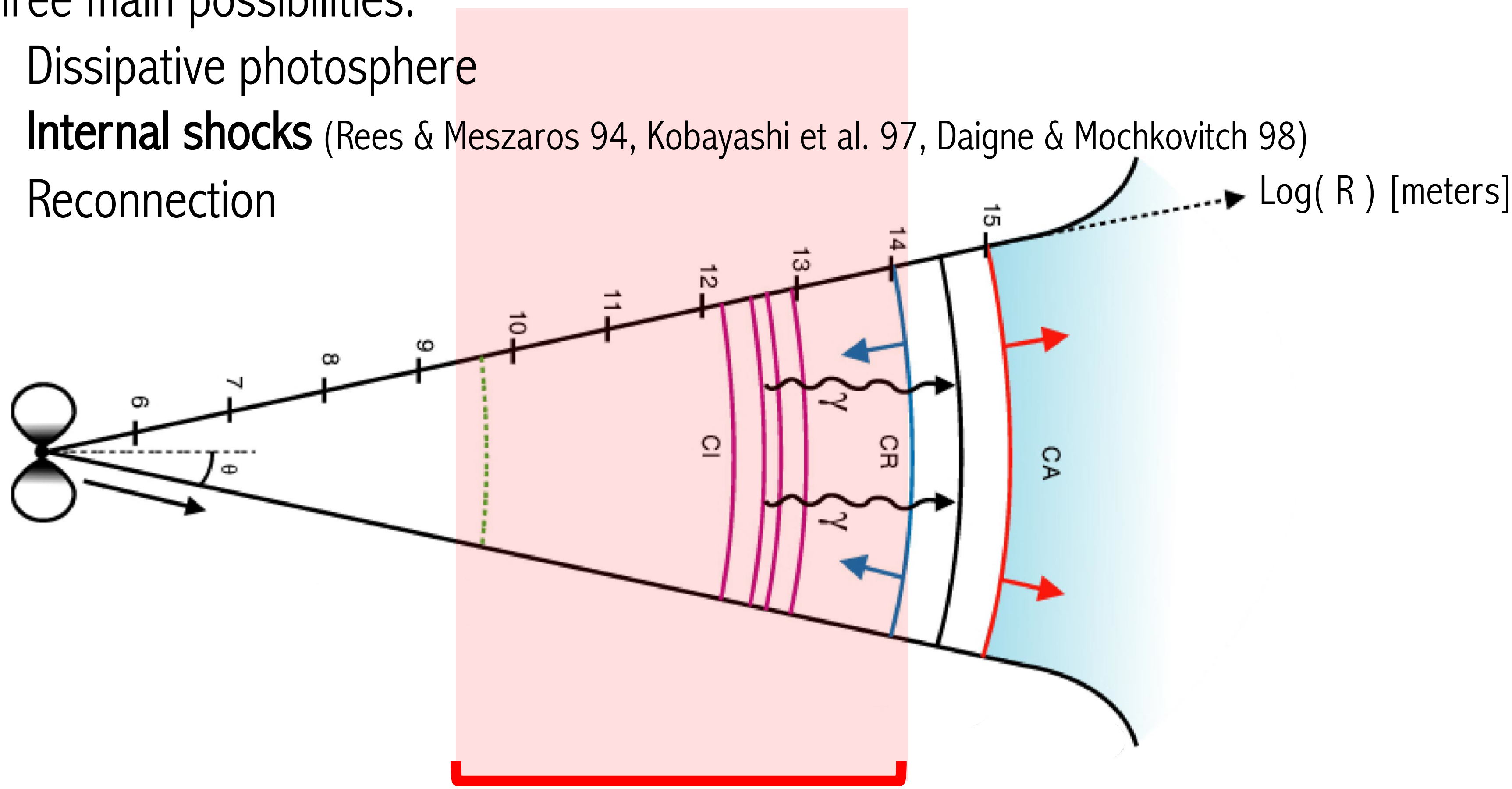
- Dissipative photosphere
- **Internal shocks** (Rees & Meszaros 94, Kobayashi et al. 97, Daigne & Mochkovitch 98)
- Reconnection

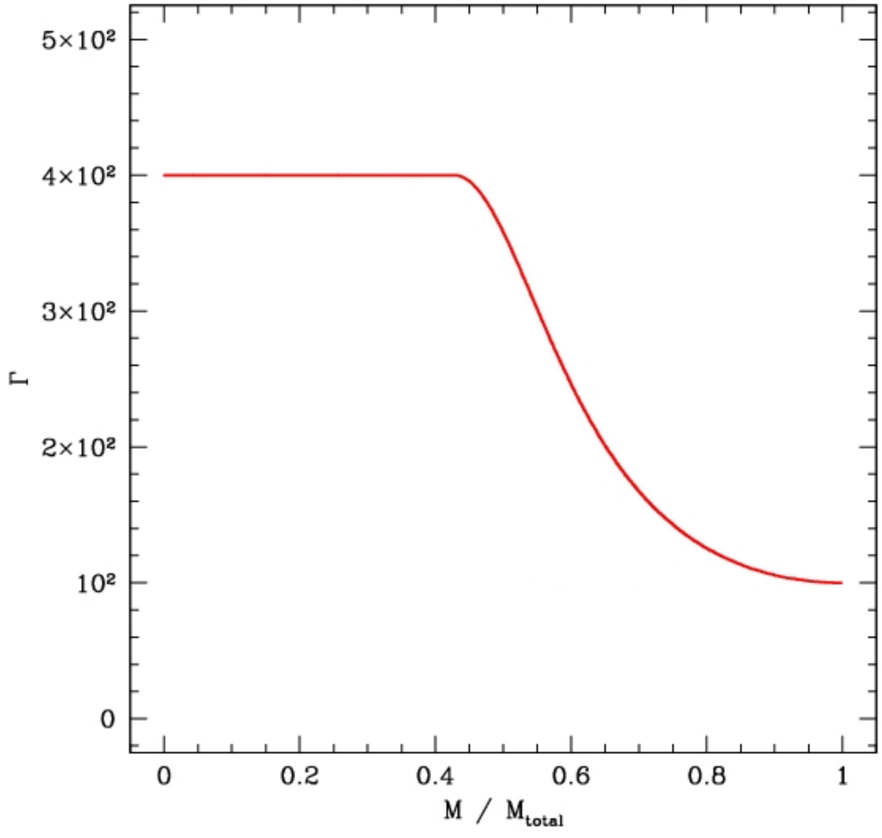


Internal Shocks: Dynamics & Emission
Single Pulse Model

Dynamics: Ballistic Model (+simplified radiation) – Daigne & Mochkovitch 1998
Dynamics: Relativistic Hydrodynamics – Daigne & Mochkovitch 2000
Detailed radiation – Bosnjak, Daigne & Dubus 2009

Dynamics

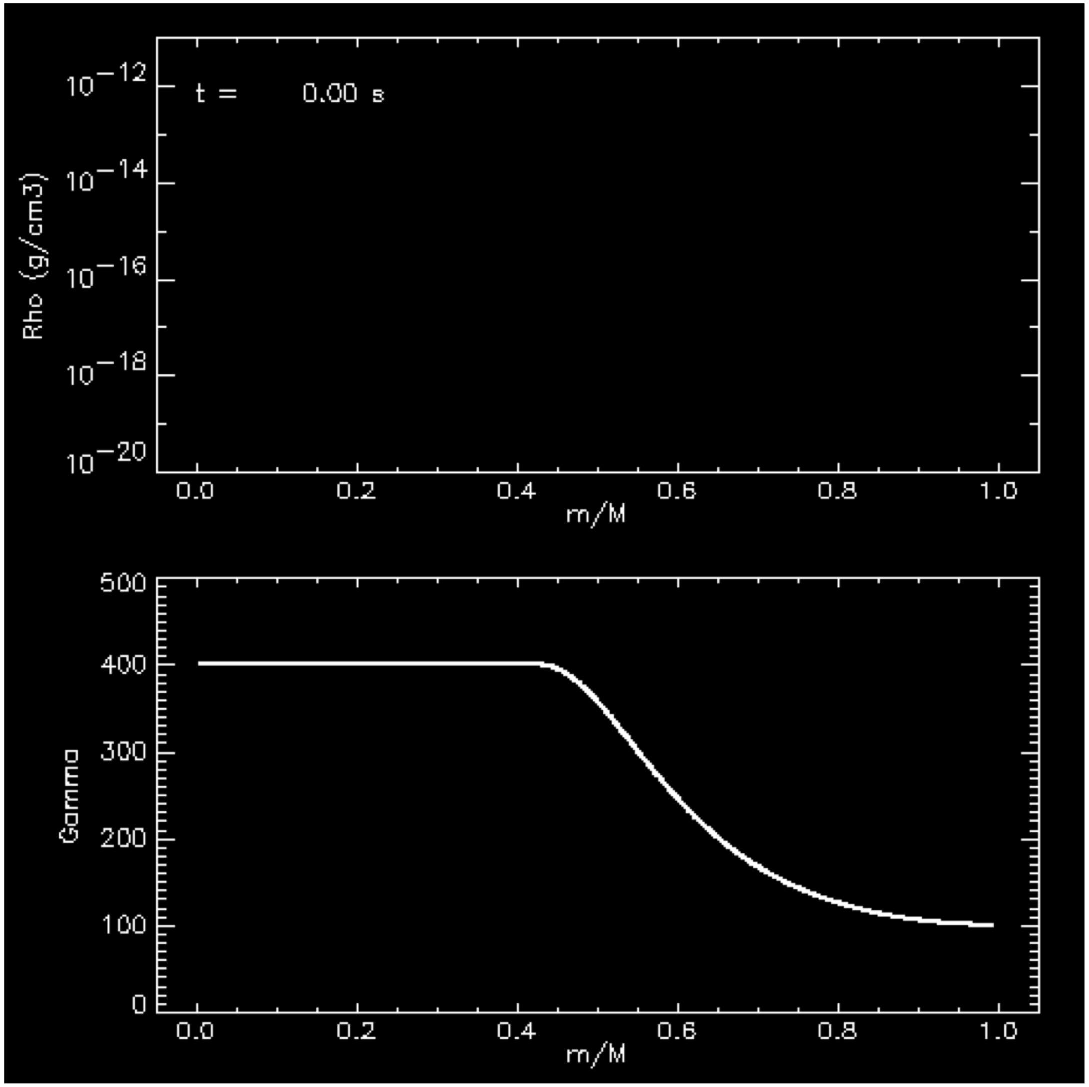
- Initial distribution of Lorentz factor :



- Ejection lasts for $t_w = 2s$
- Constant energy injection rate : $L_{kin} = 2\times10^{52}$ erg/s

Dynamics

- Dynamical evolution: (a) hydrodynamical simulation



FD & Mochkovitch 2000

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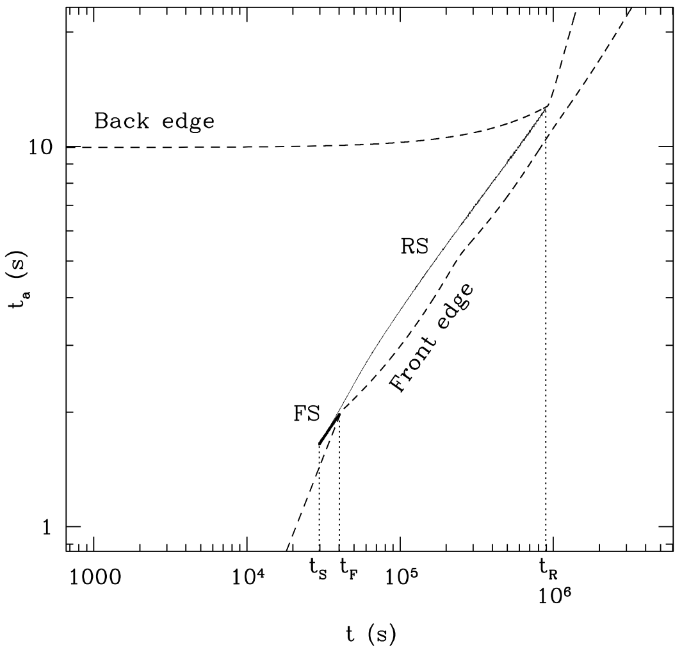

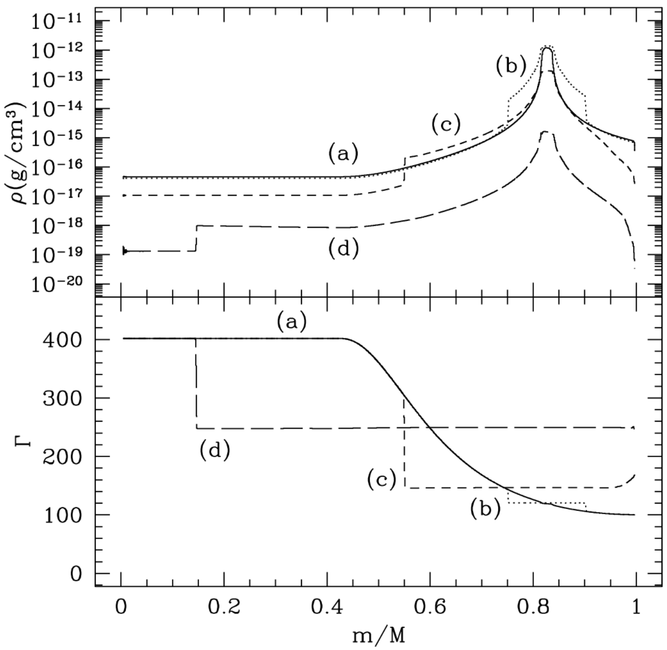

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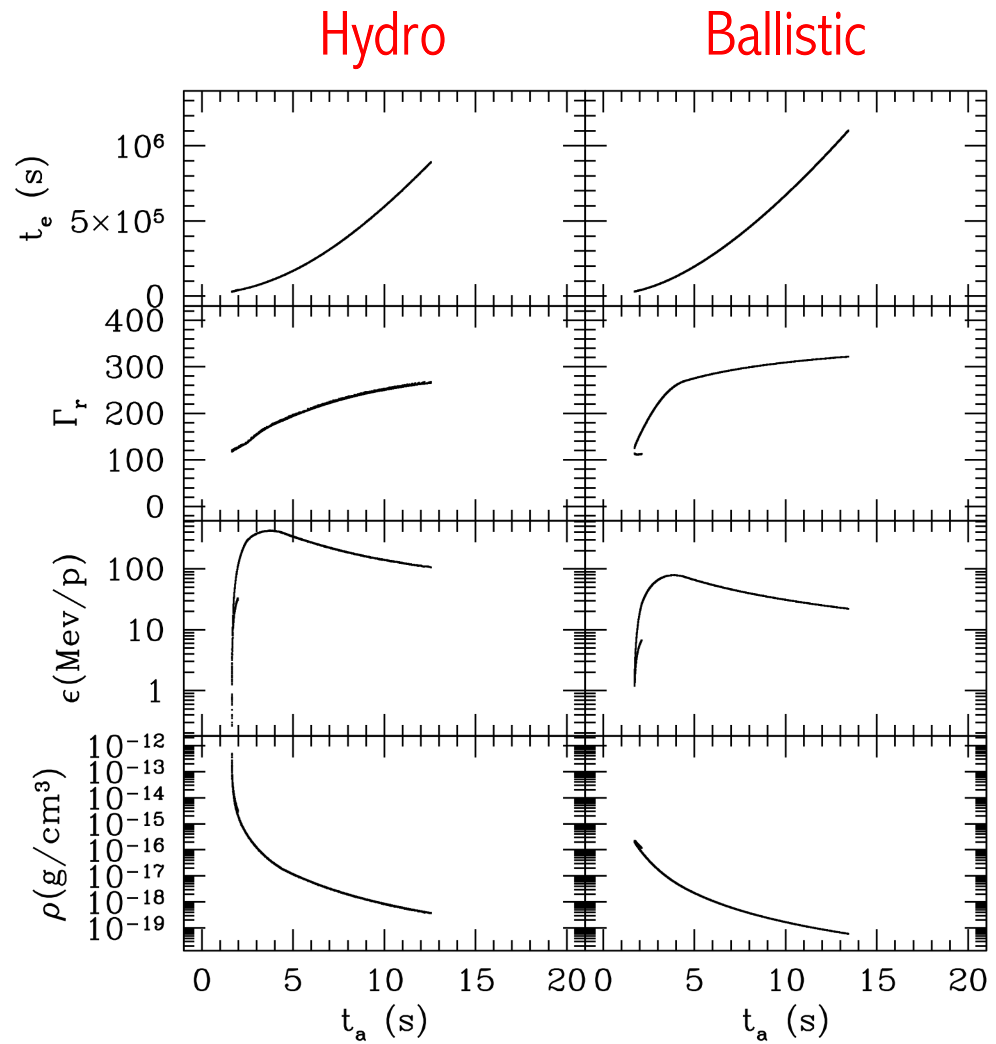
Dynamics

- Dynamical evolution: (a) hydrodynamical simulation vs (b) ballistic approximation



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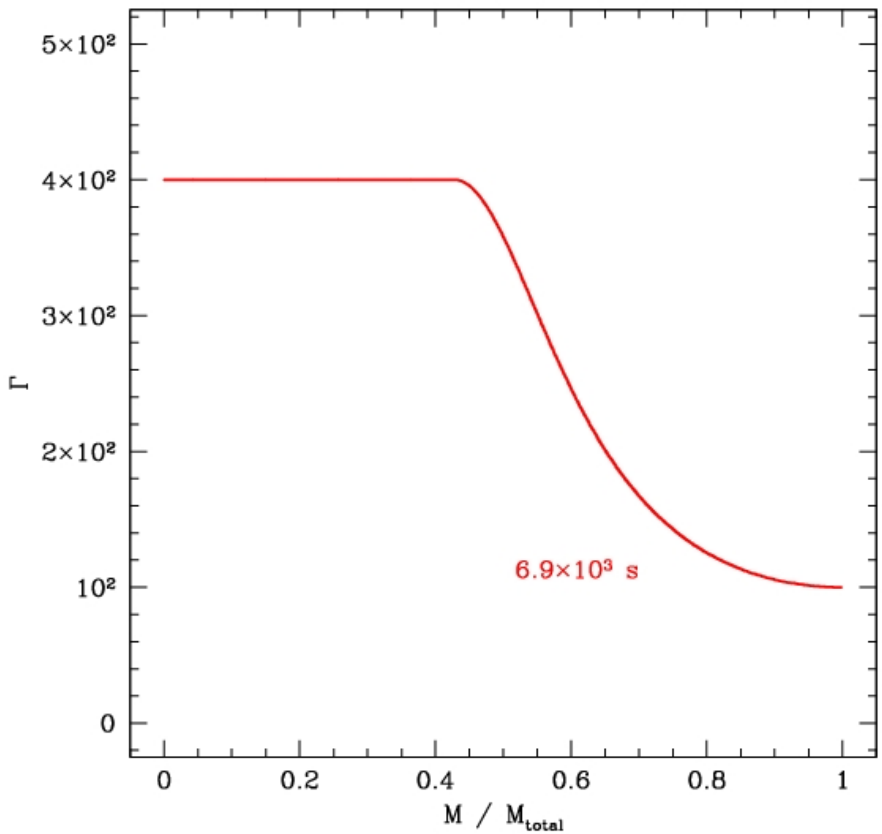
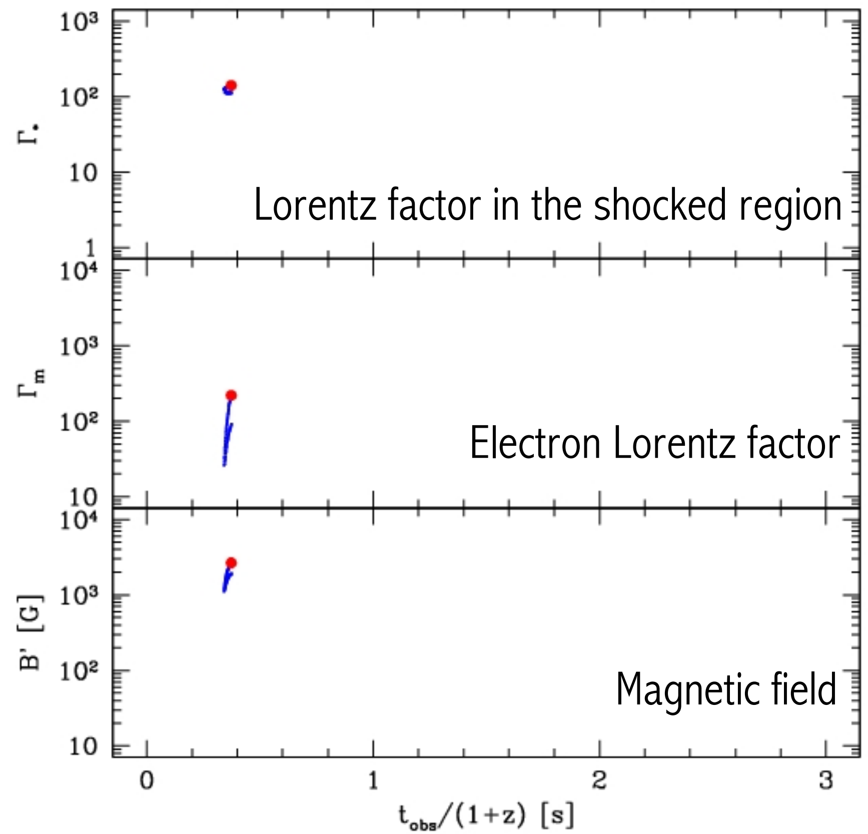
Dynamics

– Dynamical evolution: (b) ballistic approach





– Constant microphysics parameters : $\varepsilon_e = \varepsilon_B = 1/3$; $\zeta = 0.01$; $p=2.5$

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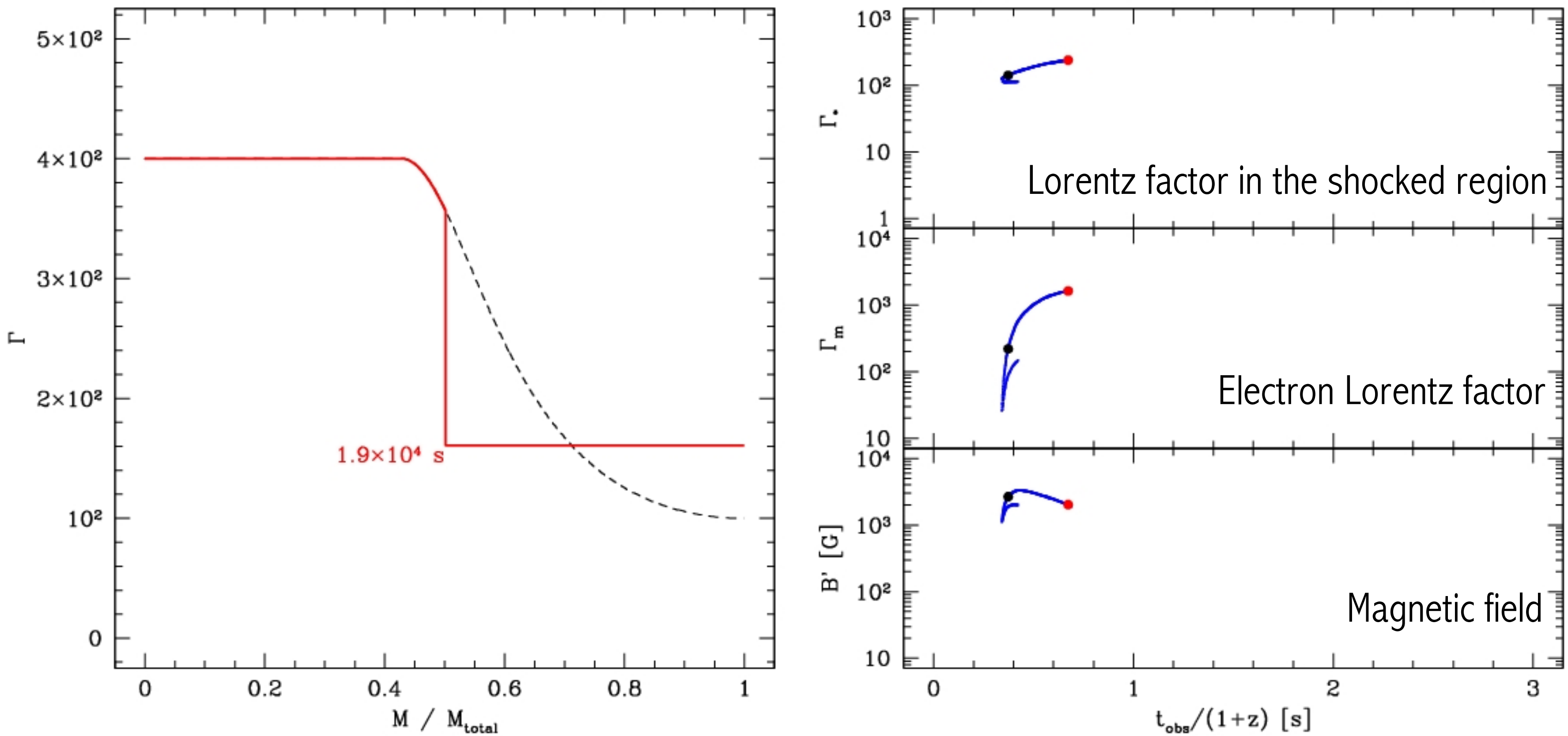

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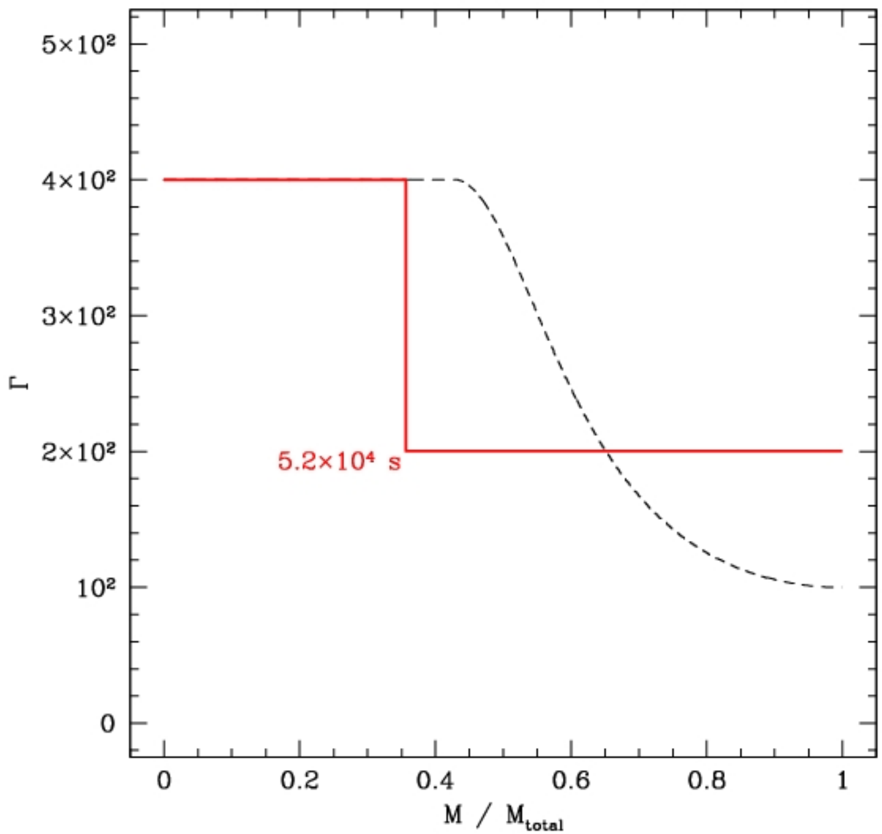

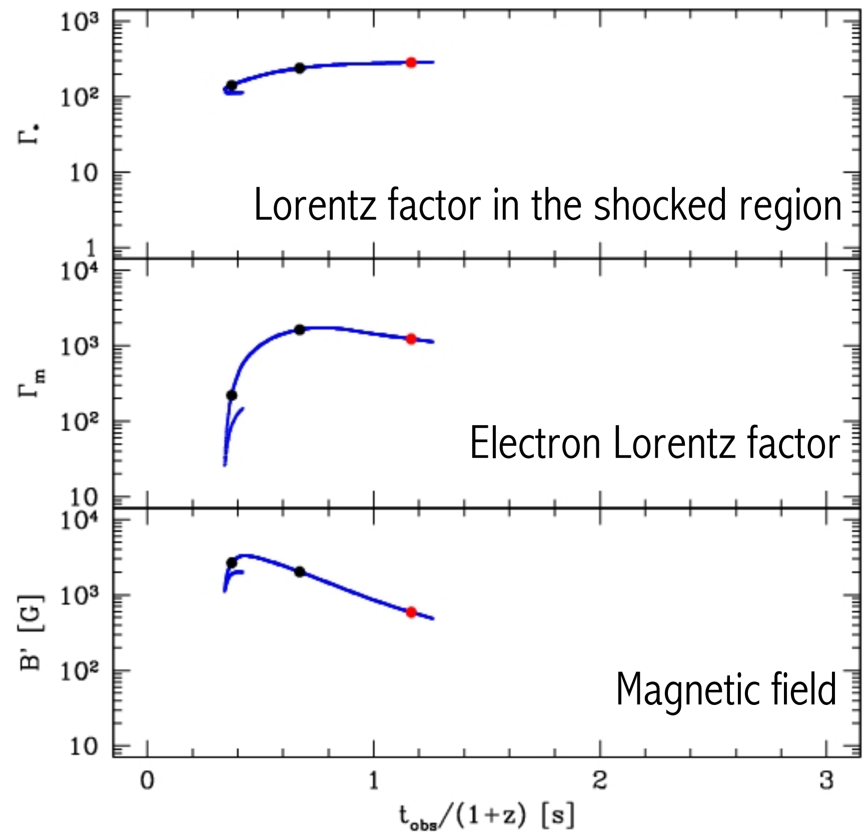

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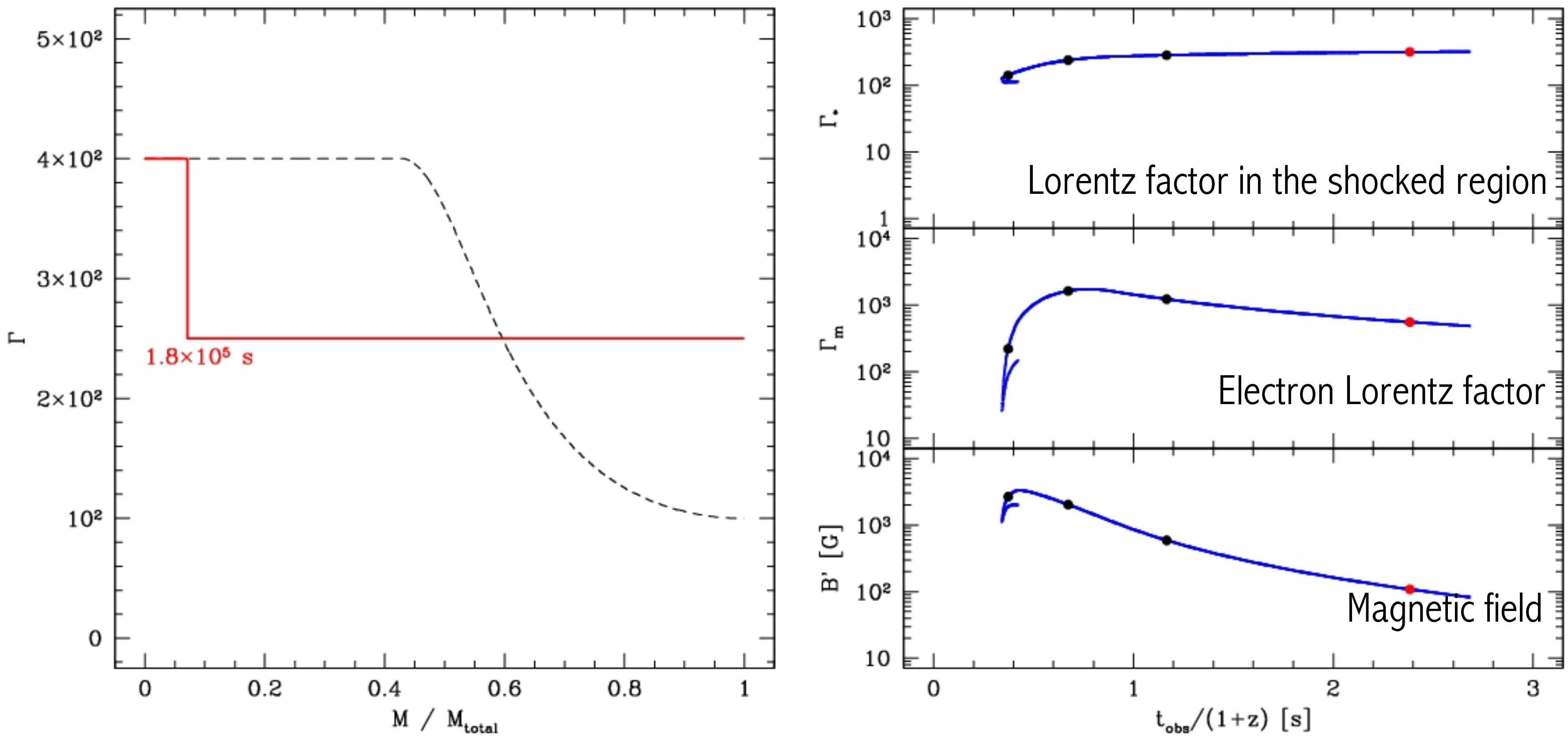

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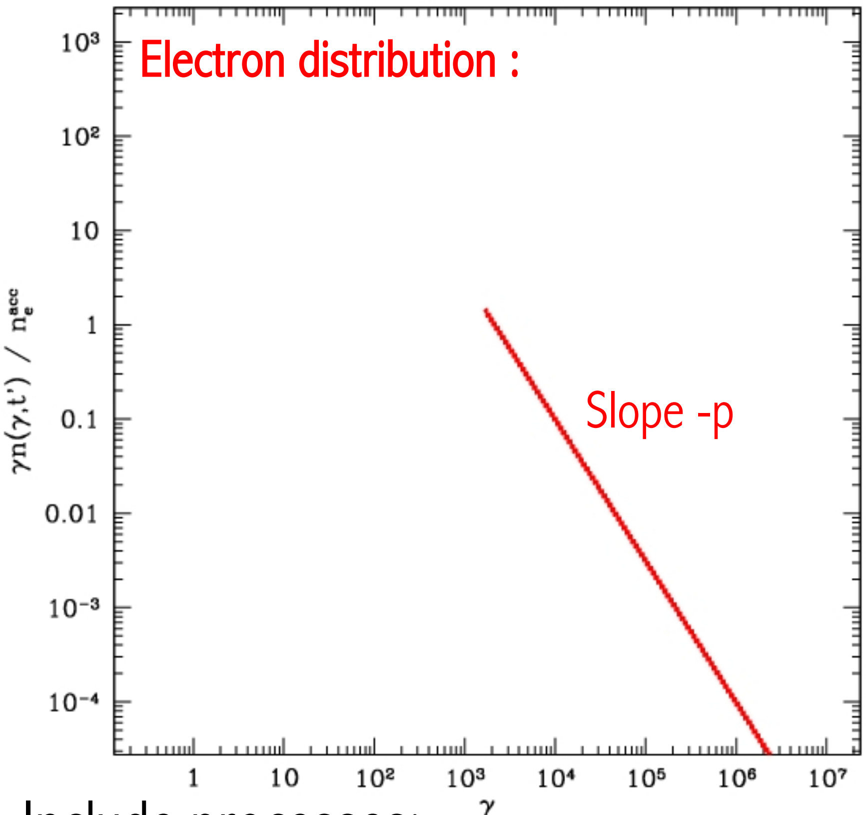
Radiation (comoving frame)

– Emission in the comoving frame: the time evolution of electrons and photons is solved (time-dependant radiative code).



– Include processes:

Adiabatic cooling ; Synchrotron radiation/self-absorption ;

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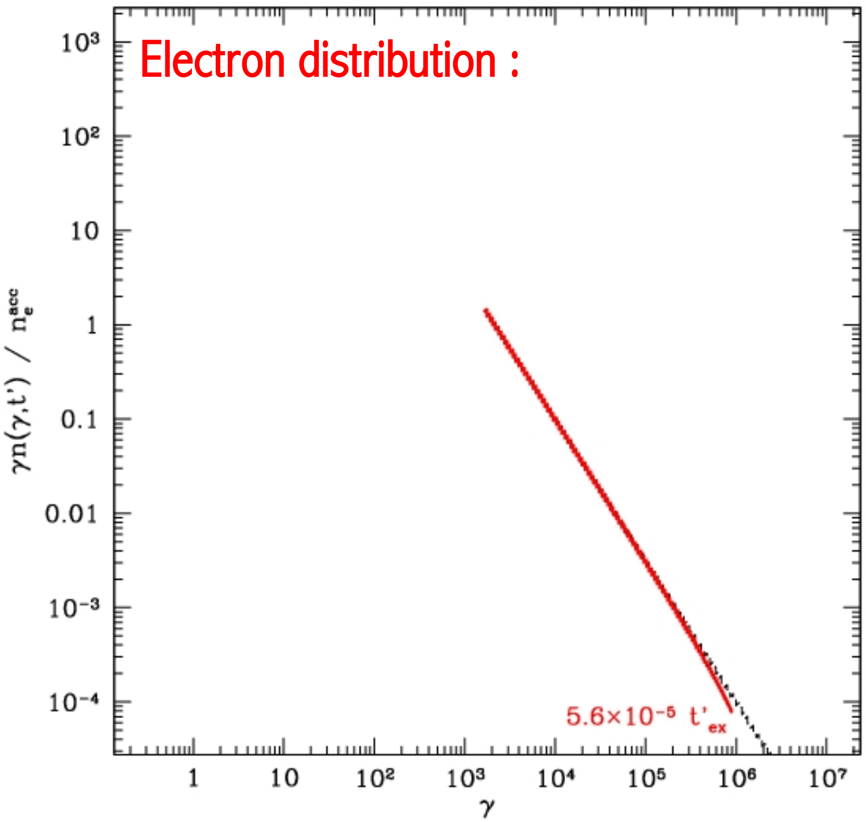

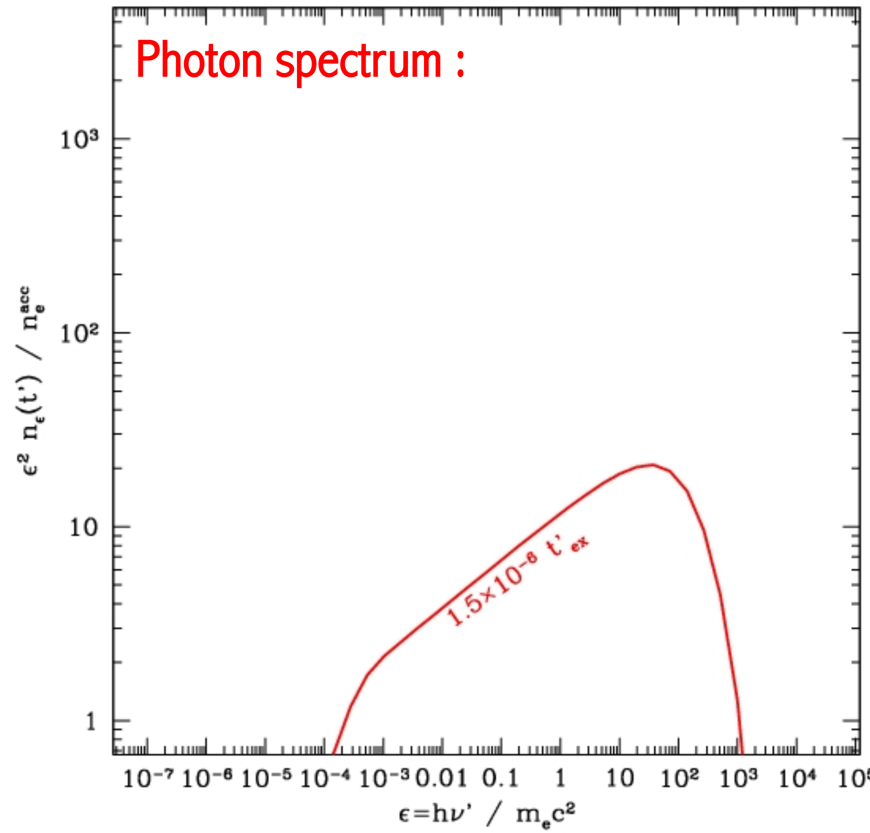

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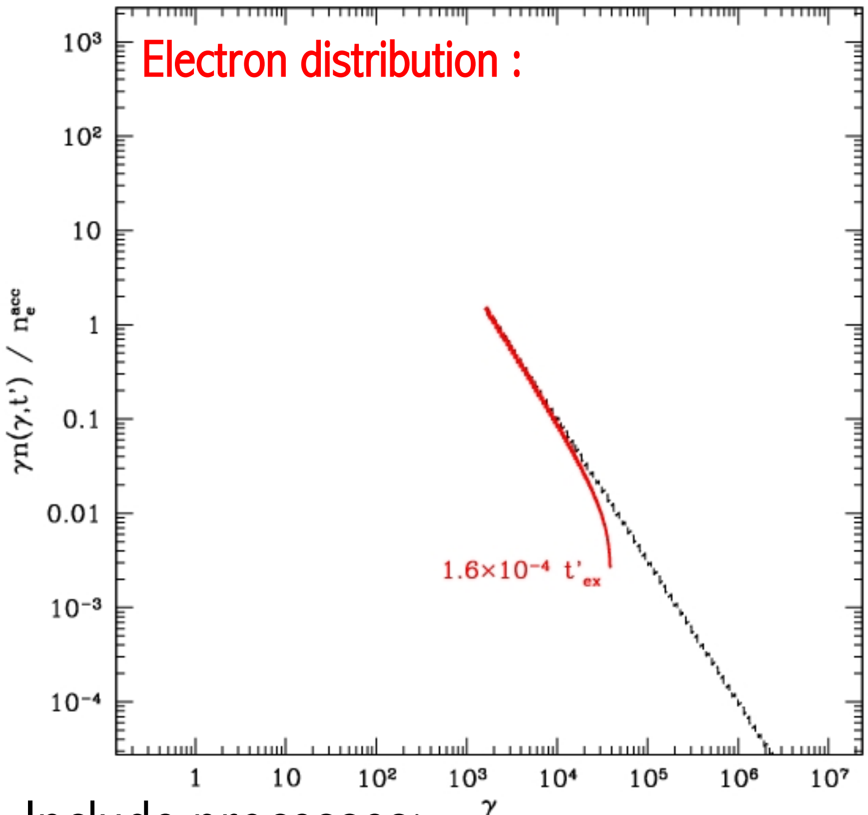

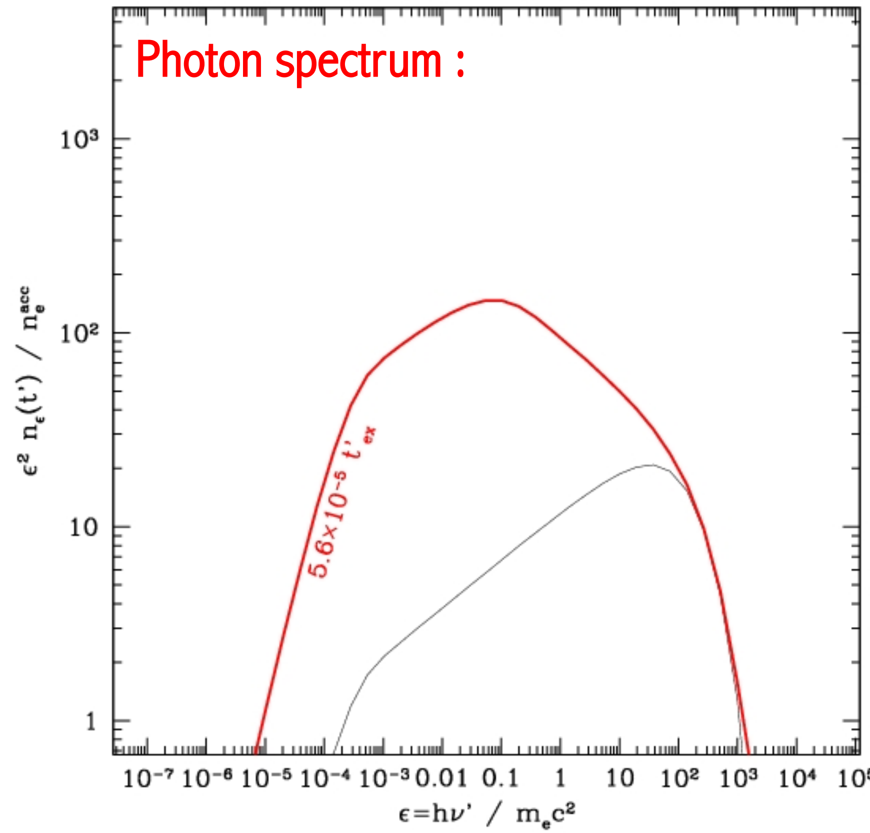

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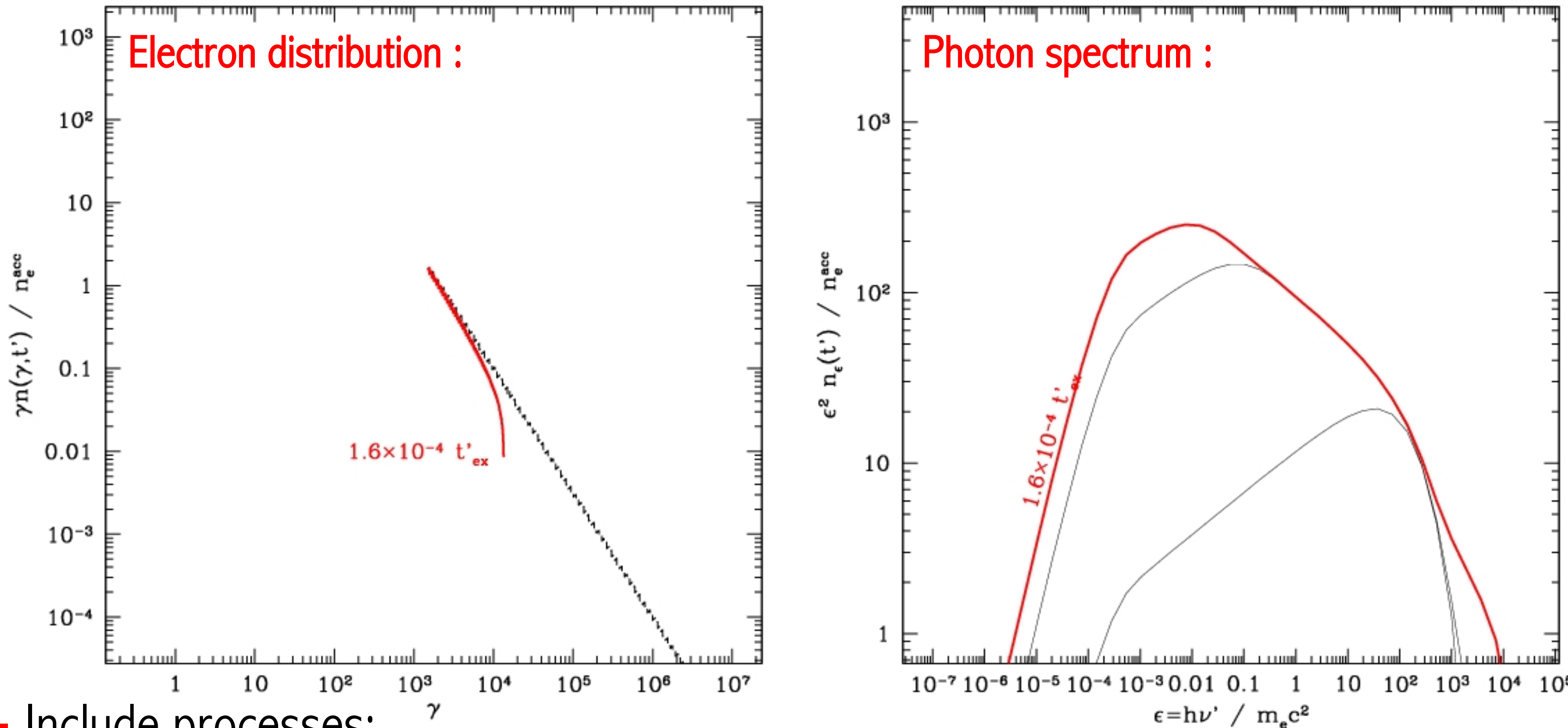

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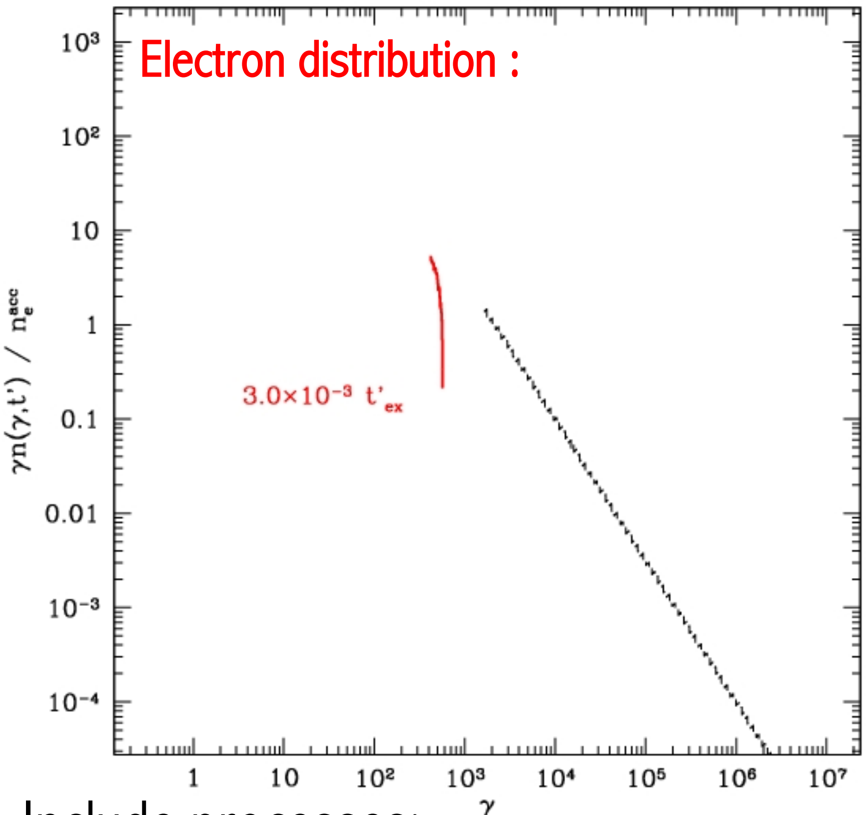

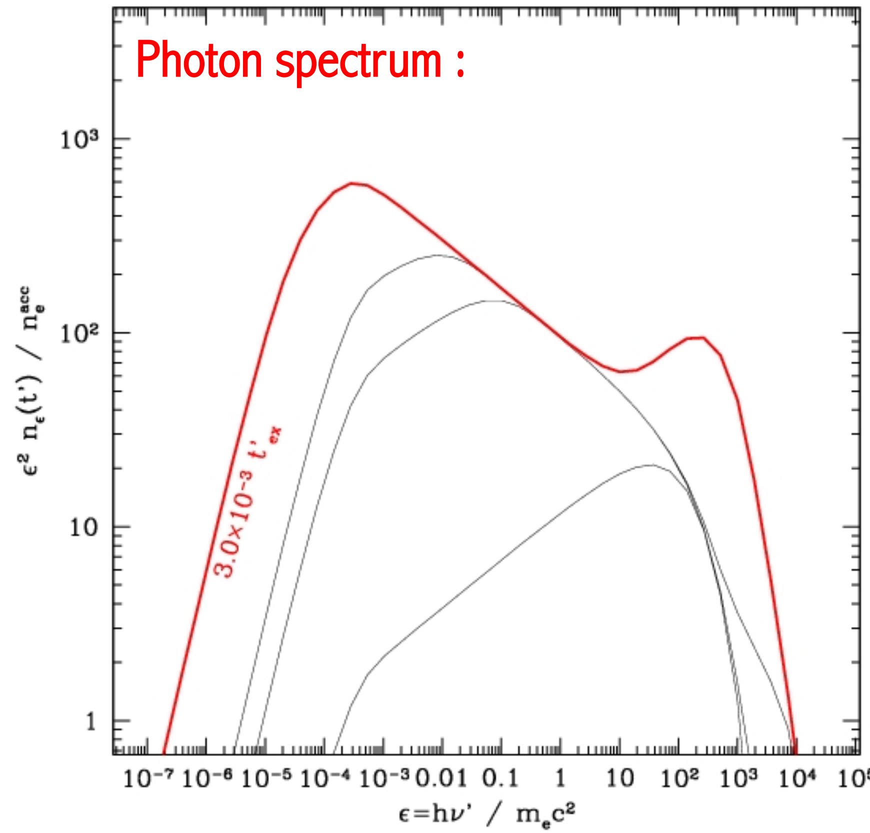

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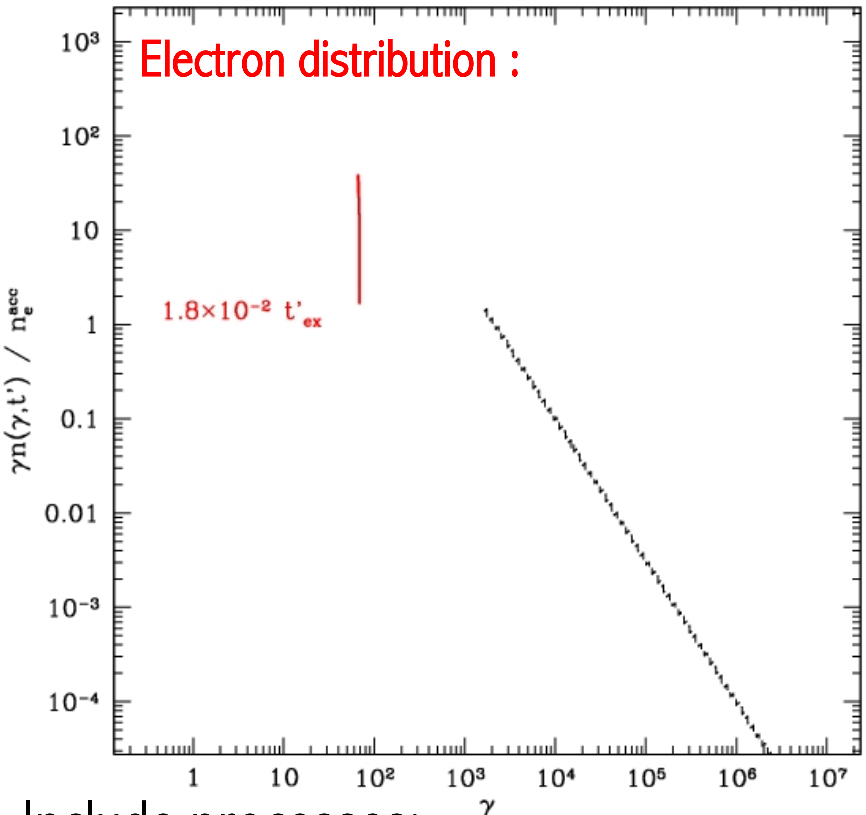

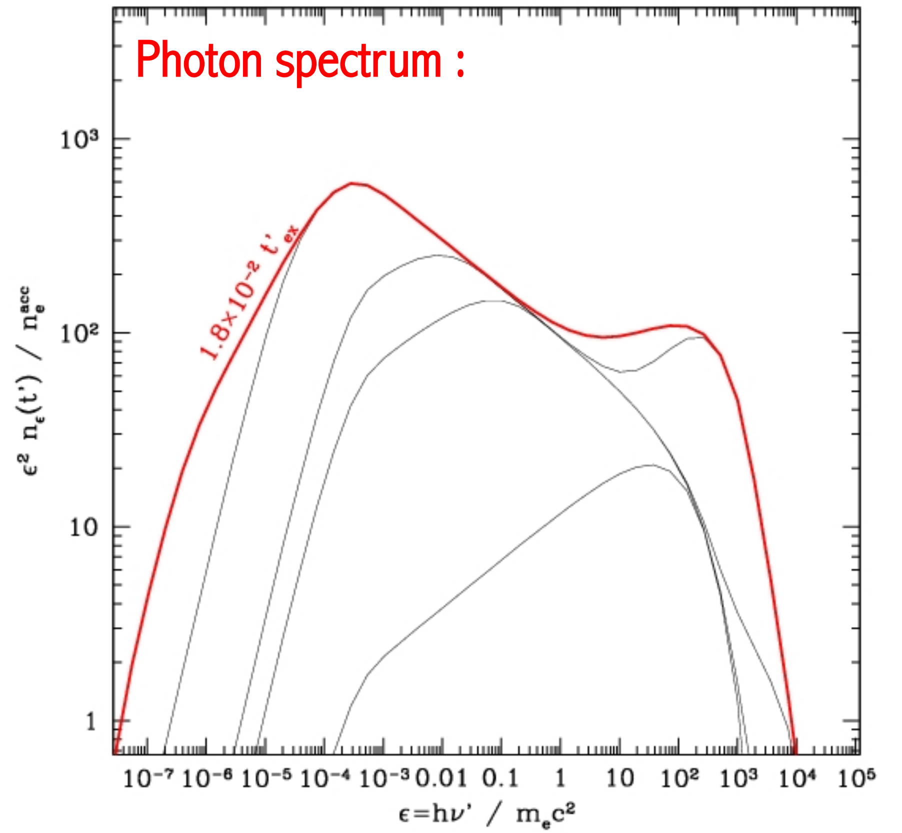

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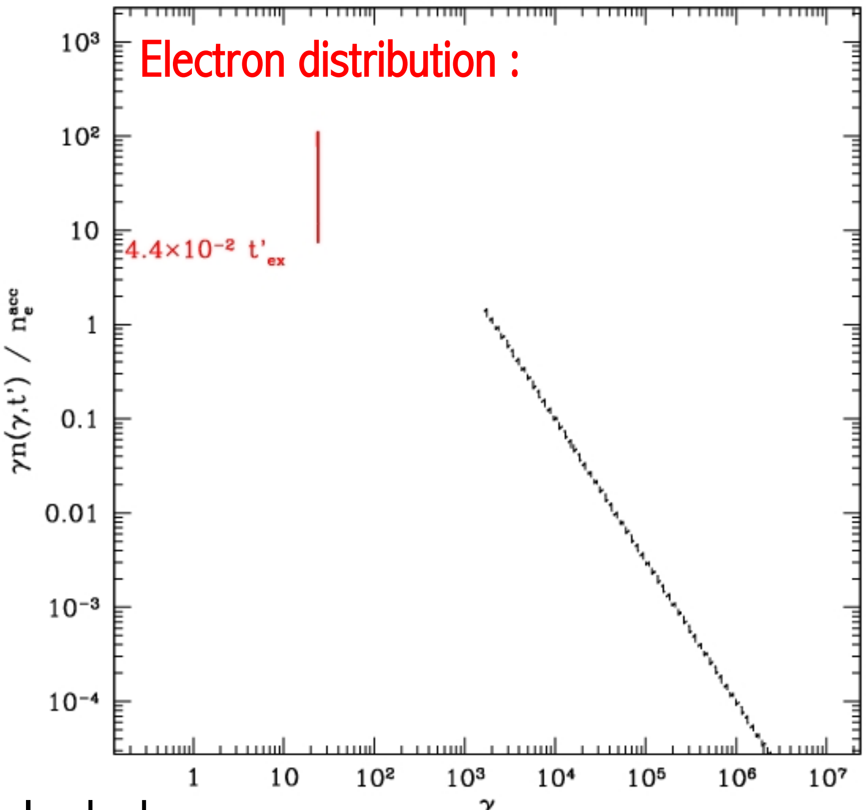

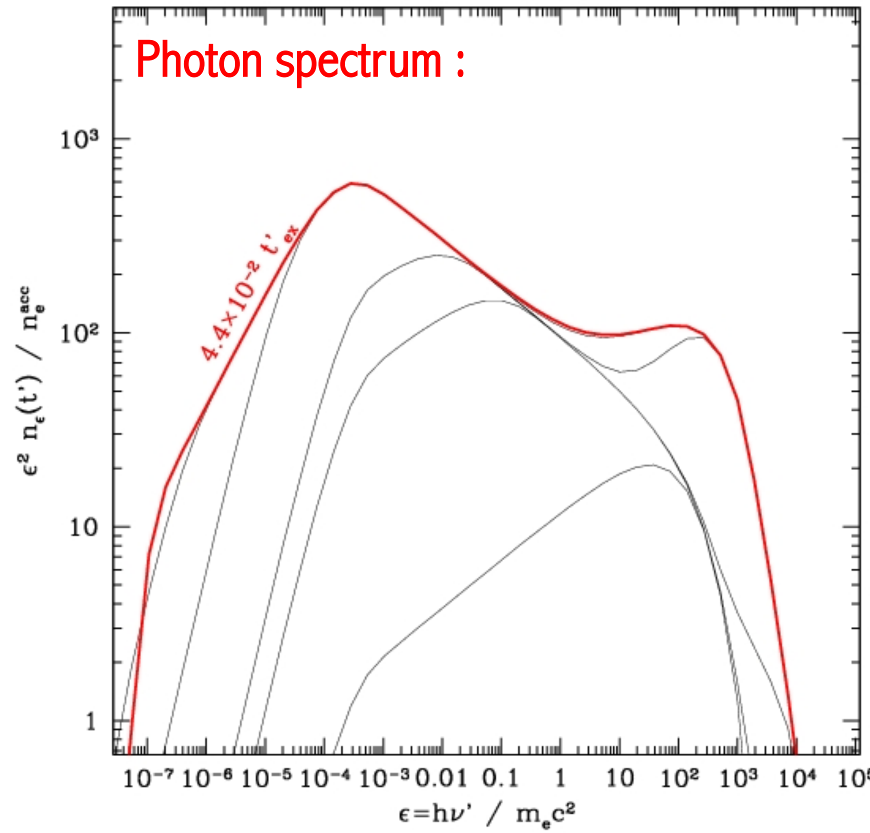

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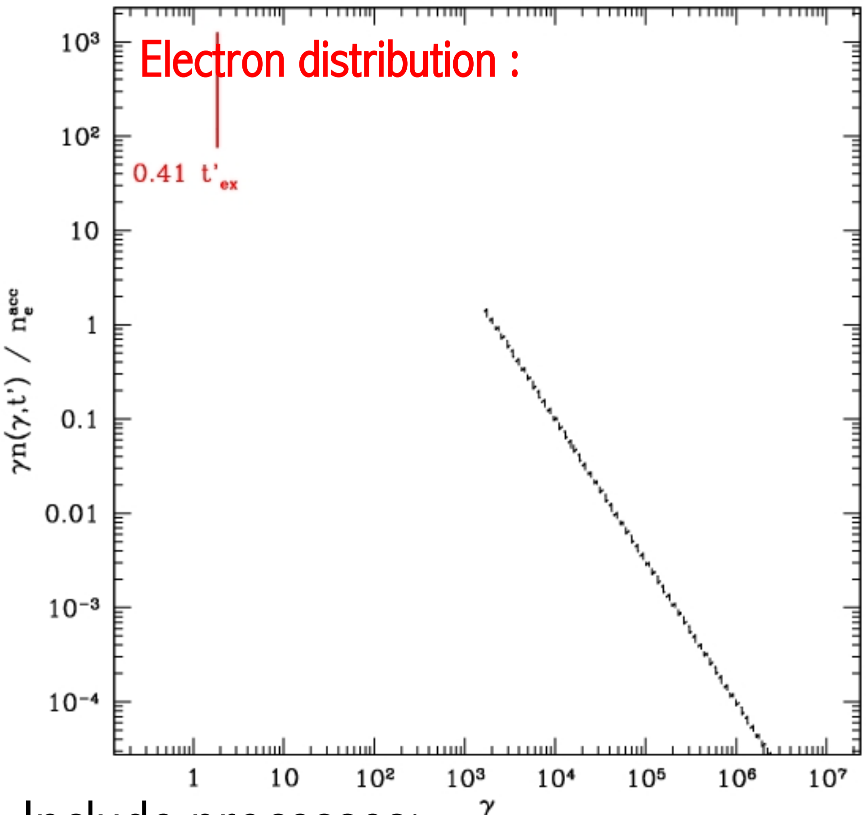

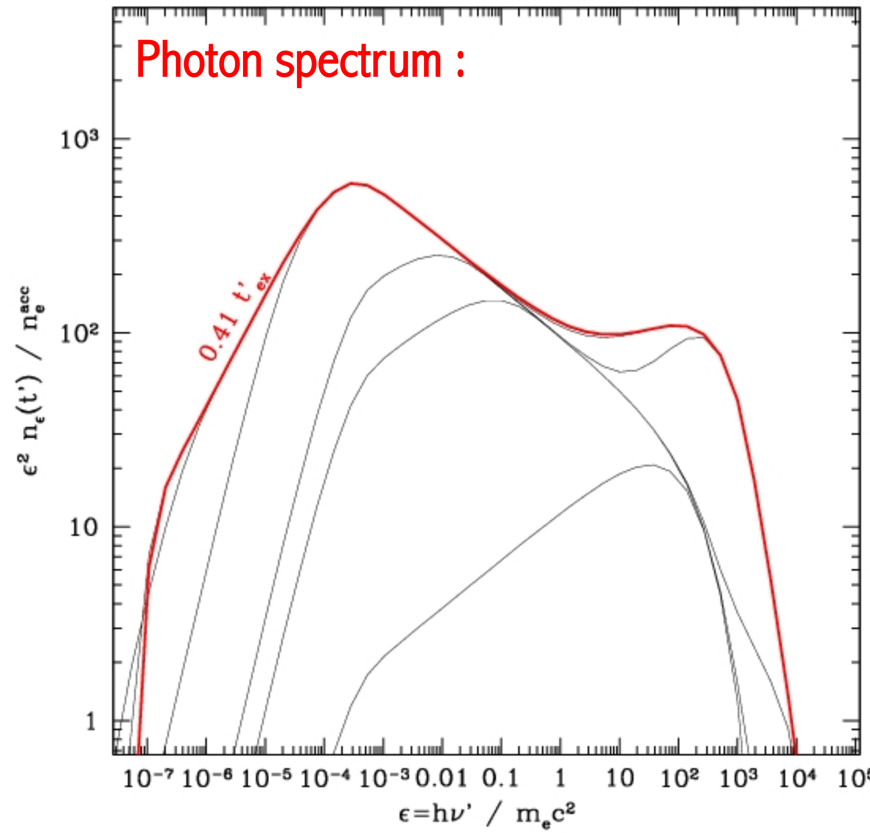

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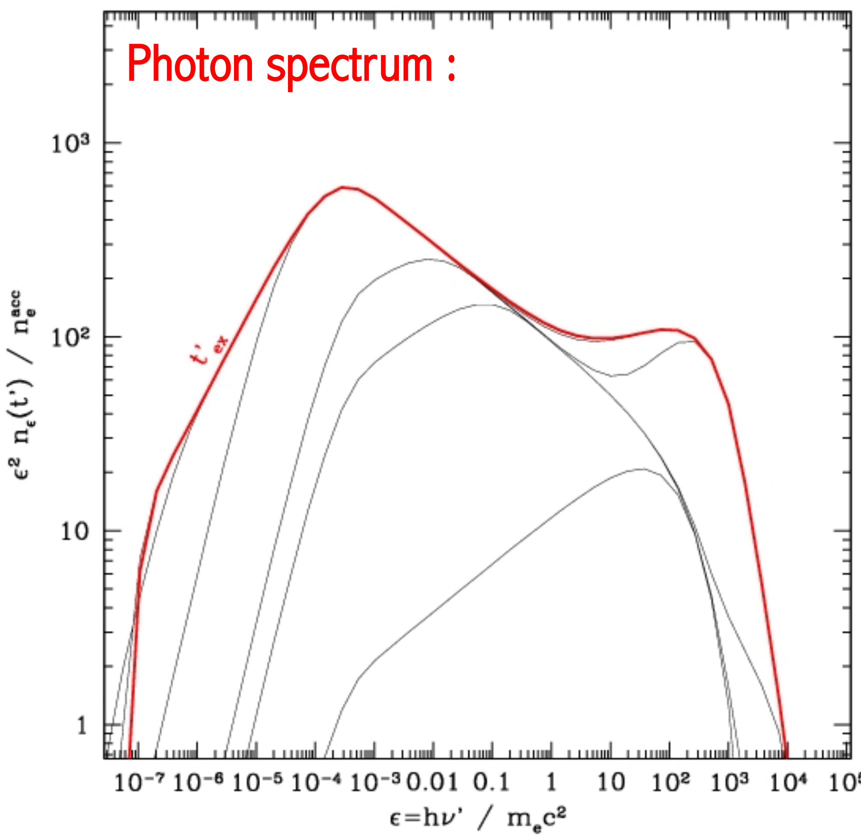
Radiation (comoving frame)

– Emission in the comoving frame:

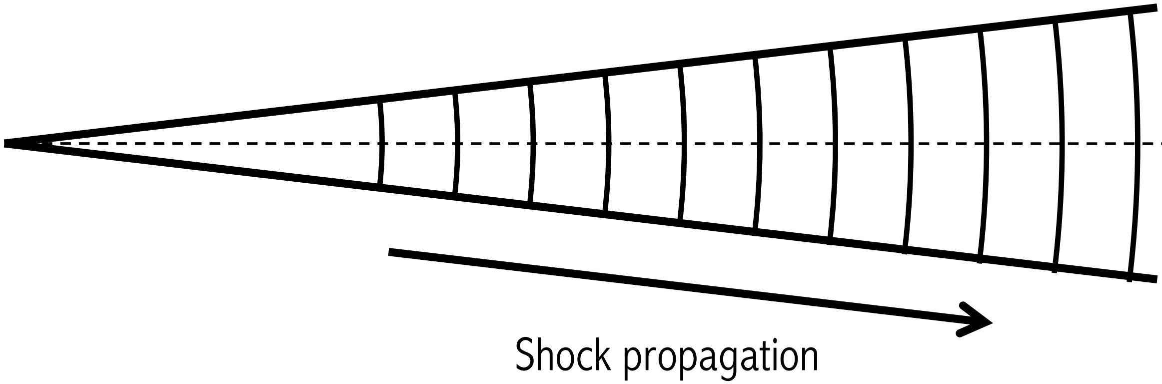
This calculation is done at all times along the propagation of each shock wave.



Radiation (observer frame)

– The time-dependant emission from all shocked regions is integrated over equal-arrival time surfaces to compute observed lightcurves and spectra

(includes: curvature of the emitting surface; relativistic Doppler shift; cosmological redshift)



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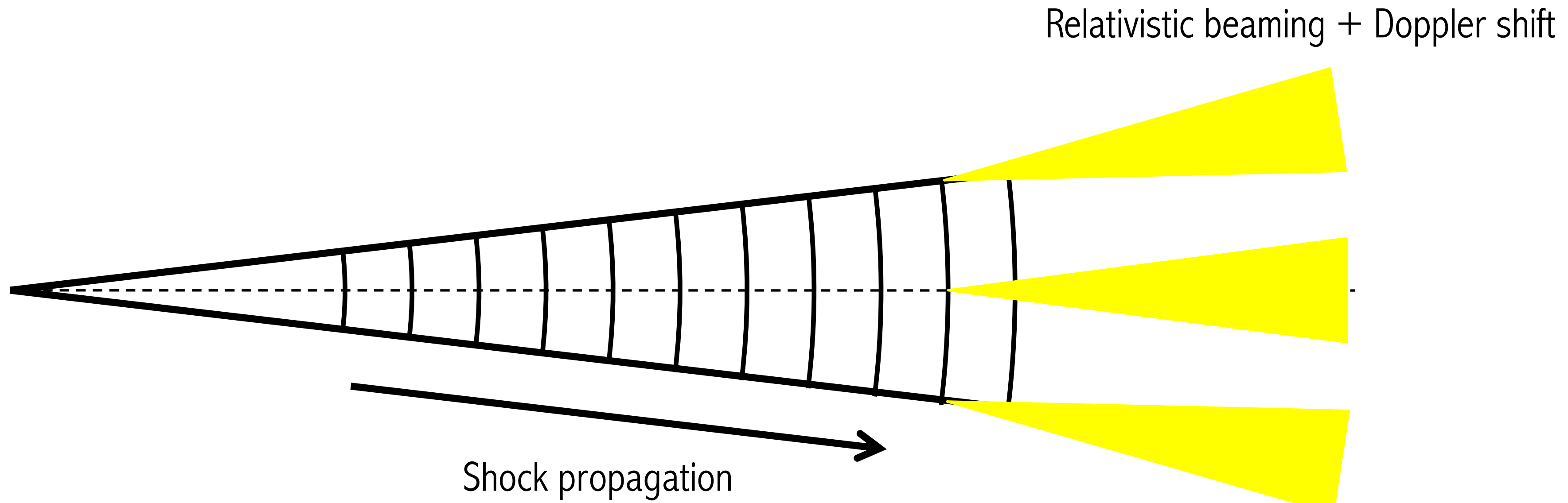

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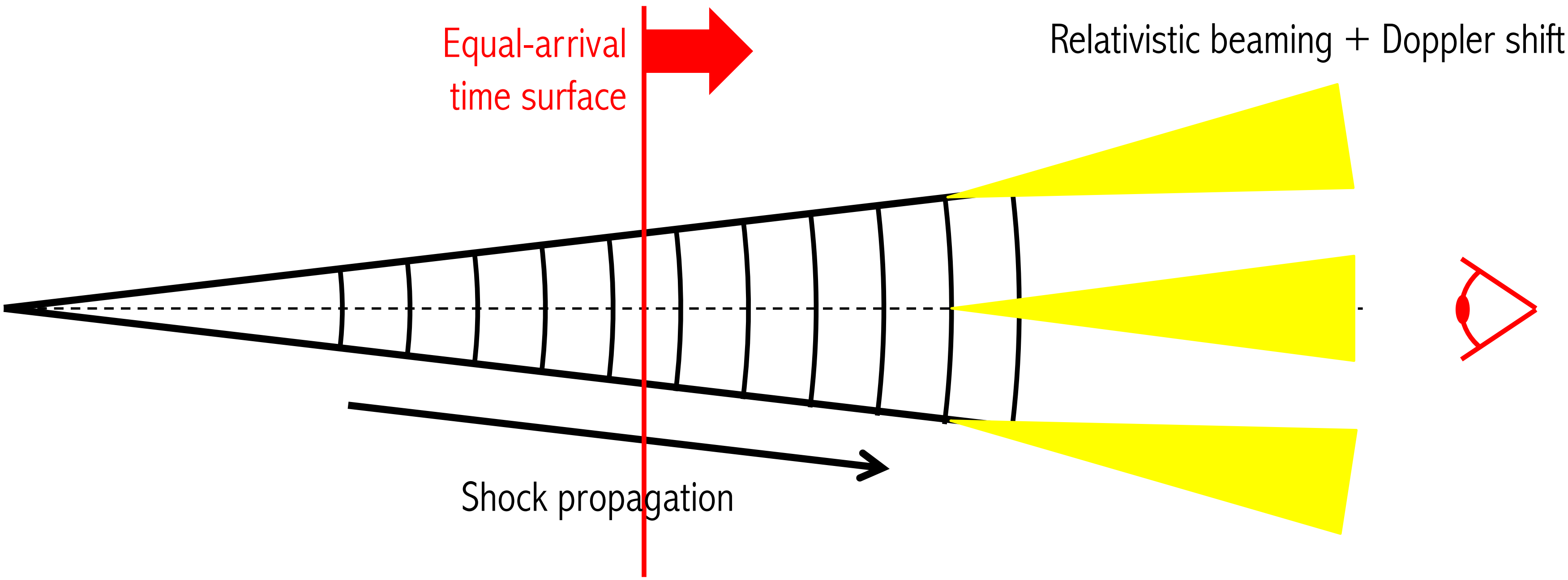


Is the prompt emission spectrum compatible with synchrotron radiation?

Expected from accelerated electrons
(shocks/reconnection)

Spectrum

Main difficulty to model the prompt GRB: spectral shape

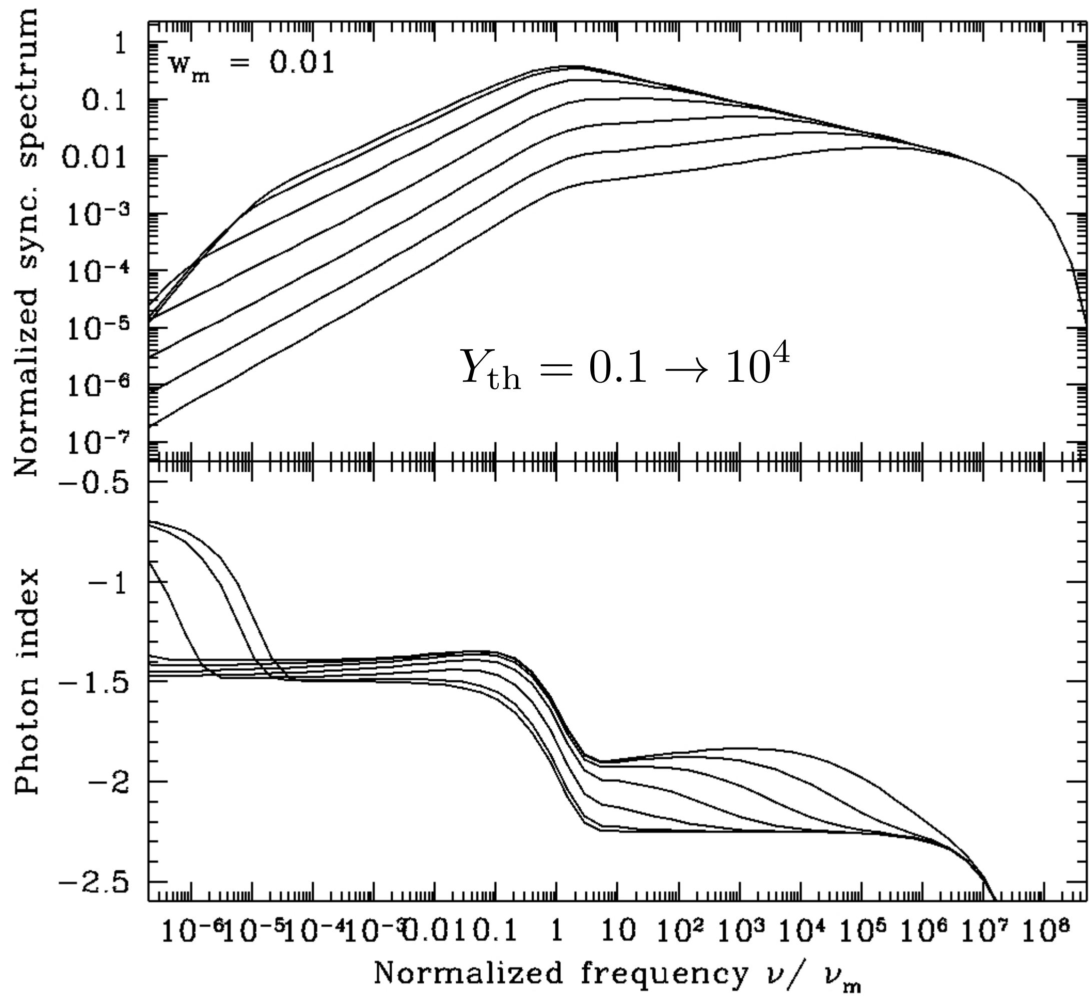
Observer low-energy photon index: ~ -1, often steeper

Low-energy photon index in fast cooling synchrotron spectrum?
(or other equivalent related diagnostics)

-3/2 : pure fast cooling synchrotron
~ -1 : fast cooling synchrotron + inverse Compton in KN regime
(Derishev et al. 01 ; Bosnjak et al. 09 ; Wang et al. 09 ; Daigne et al. 11)
-2/3 : marginally fast cooling synchrotron (Daigne et al. 11 ; Beniamini & Piran 13)
-1 $\longrightarrow$ -0.5 : fast cooling synchrotron + IC in decaying magnetic field
(Pe'er & Zhang 06 ; Derishev 07 ; Lemoine 13 ; Zhao et al. 14,
Daigne & Bosnjak in preparation)

Fast cooling synchrotron spectrum

IC scatterings in
KN regime:
steeper synchrotron slope



$$w_{\rm m} = \Gamma_{\rm m}\frac{h\nu'_{\rm m}}{m_{\rm e}c^2}$$

$w_{\rm m} \ll 1$ Thomson

Daigne, Bosnjak & Dubus 2011

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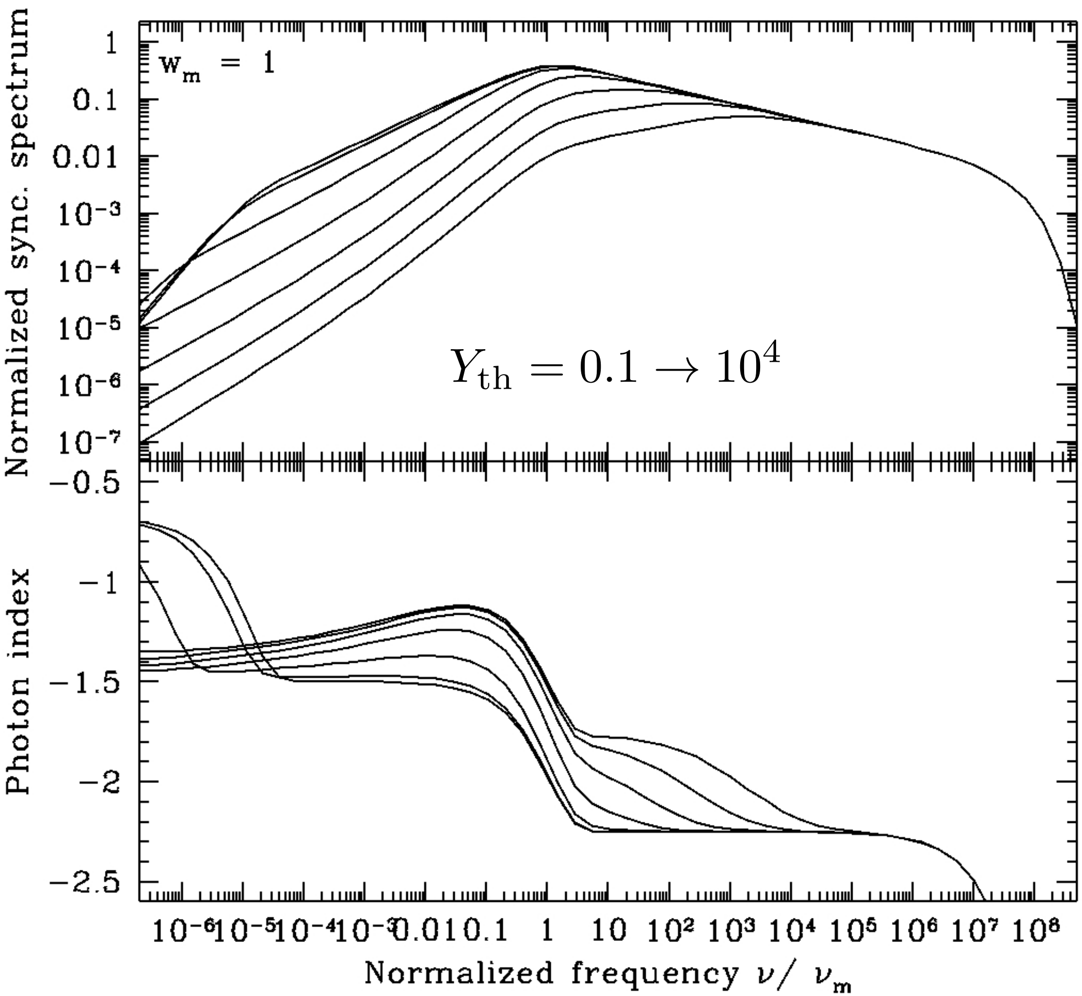

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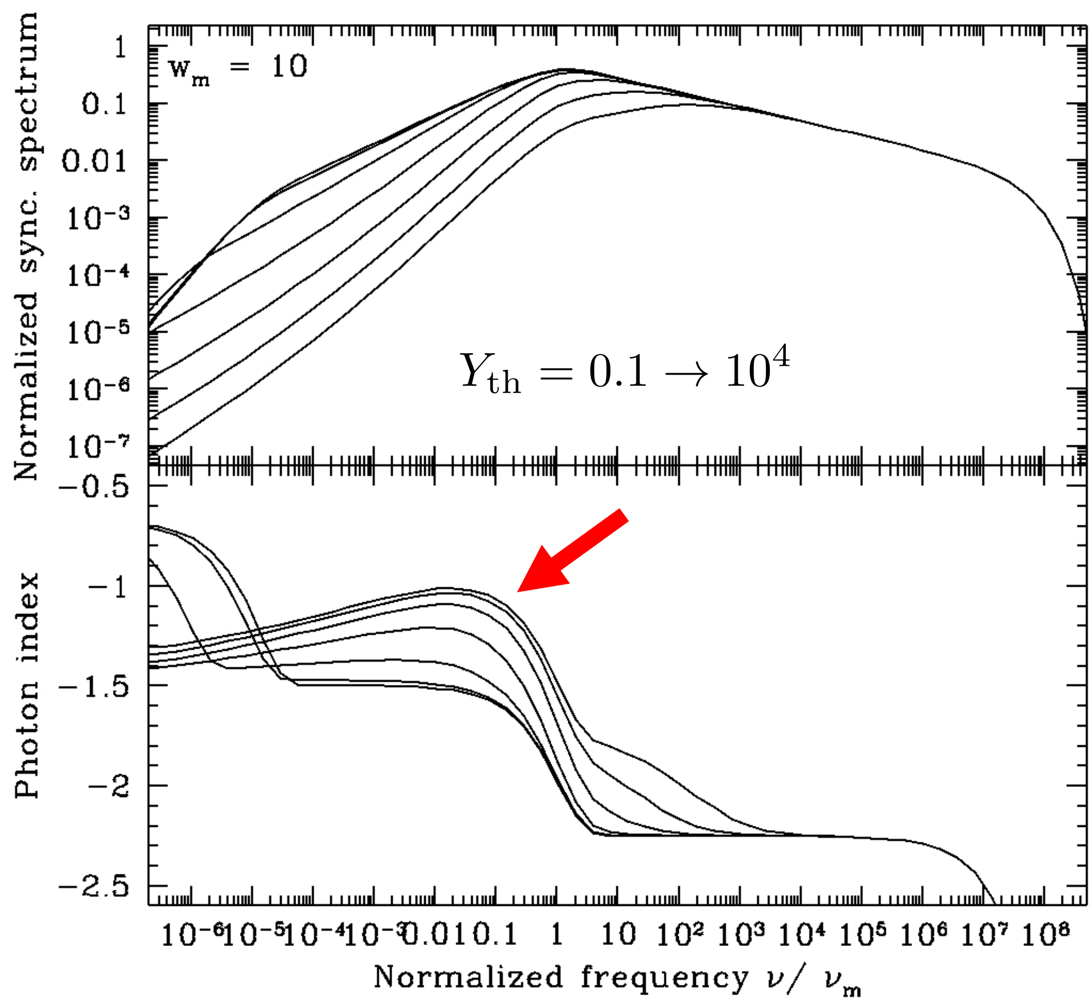

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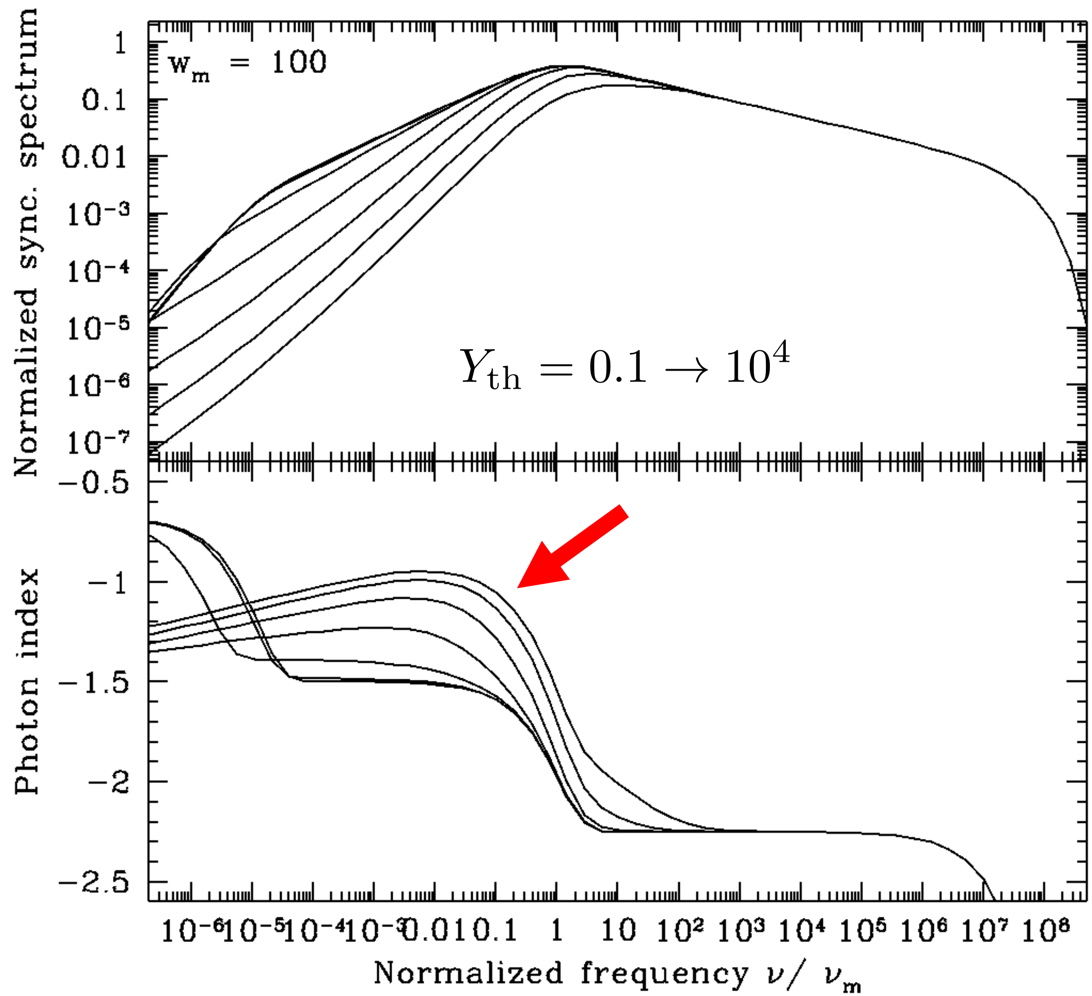

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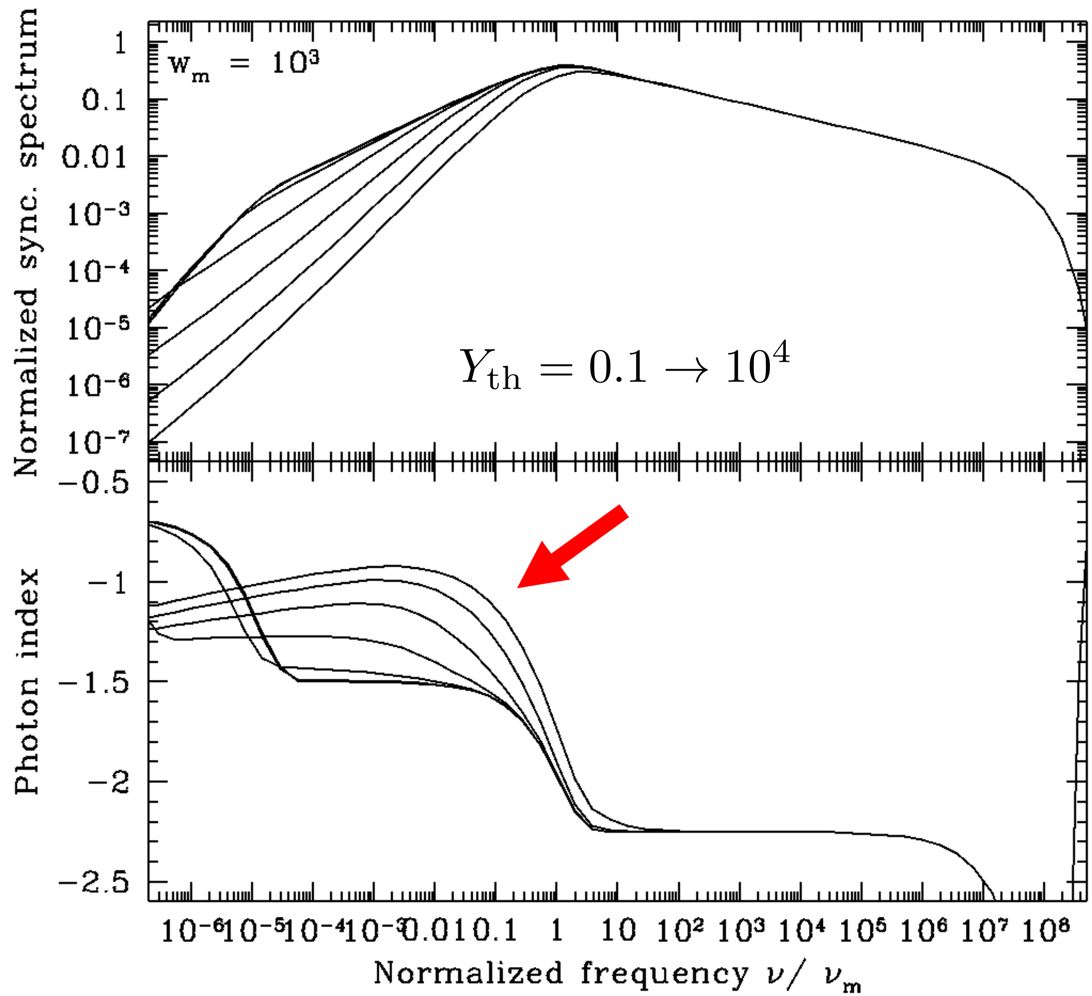

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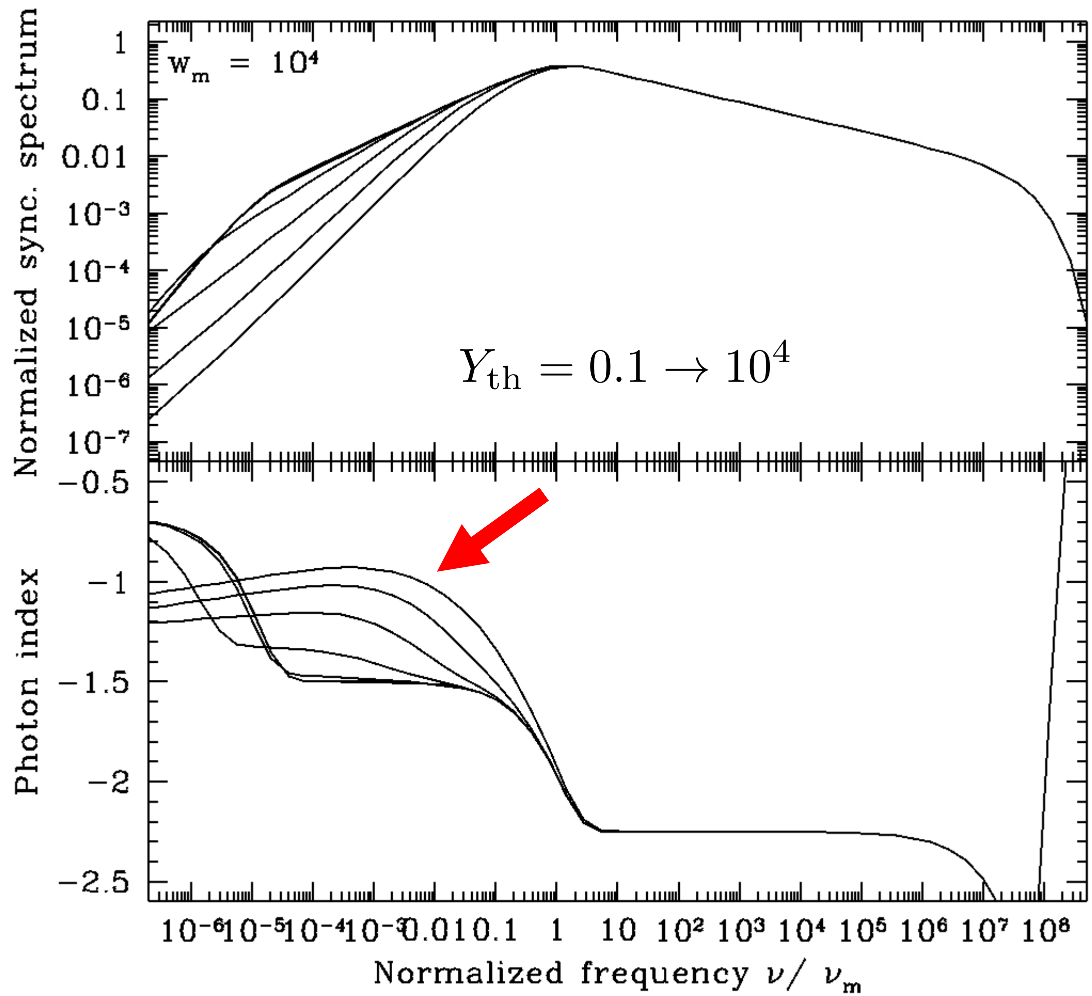

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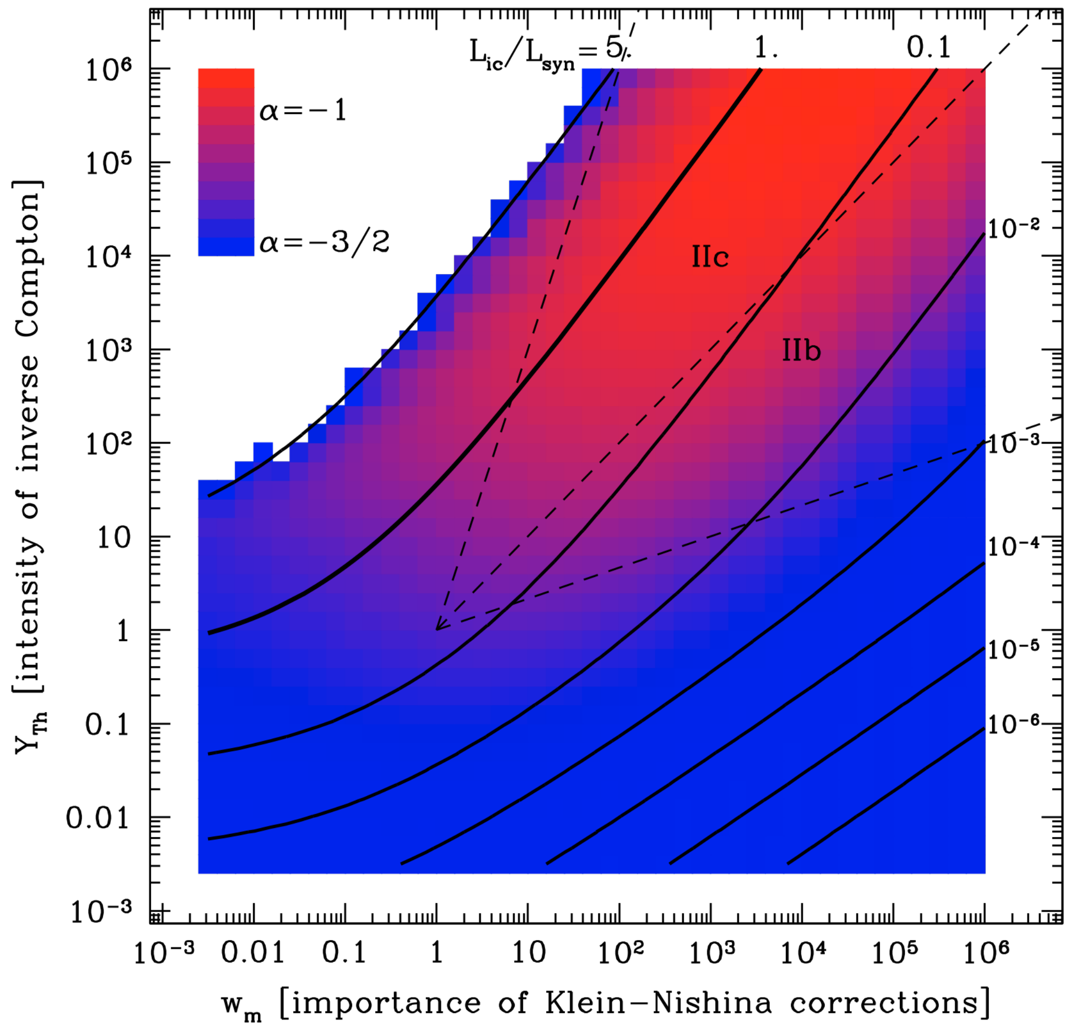


Daigne, Bosnjak & Dubus 2011

Fast cooling synchrotron spectrum

No decay

Effect of B decay

(e.g. Keshet et al. 11)

Here: exponential decay

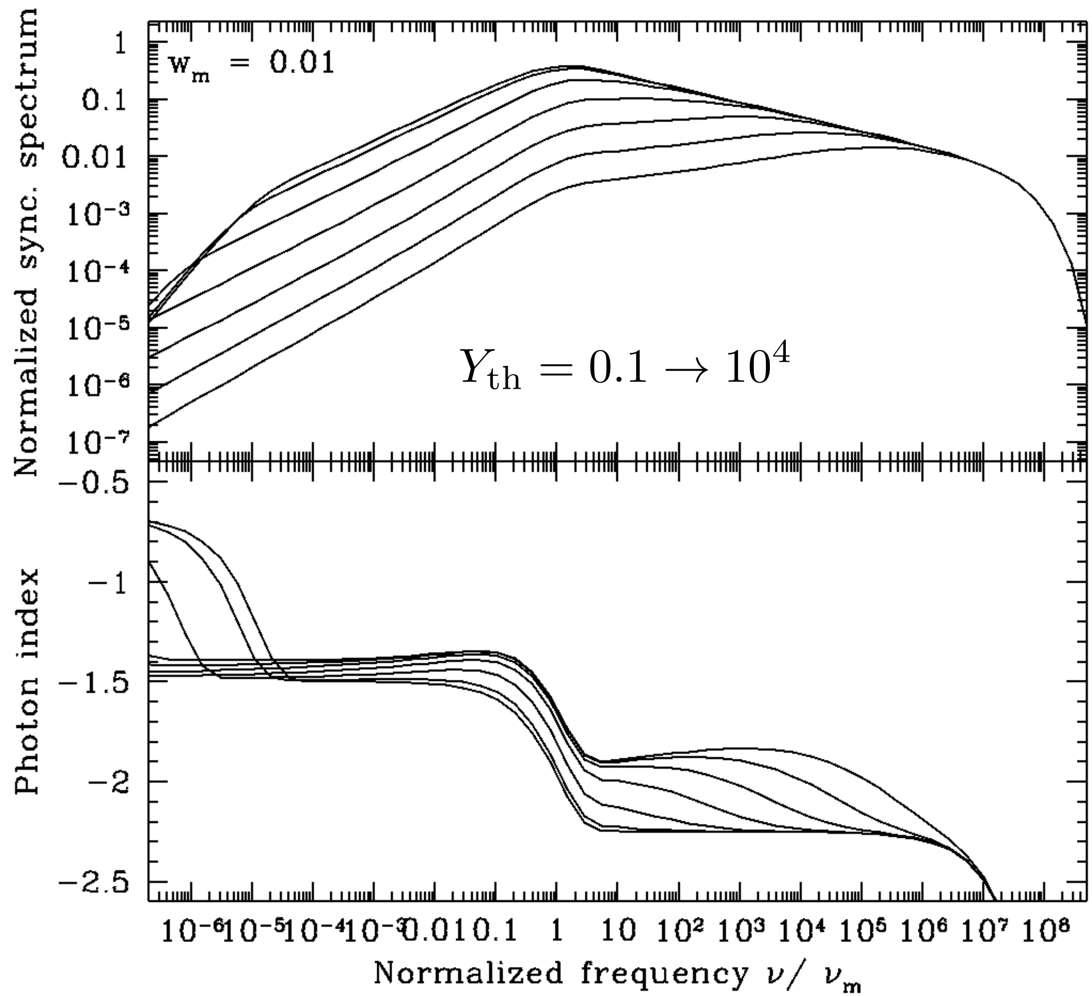
$$B = B_0 e^{-t'/\tau_B}$$

$$\tau_\mathrm{B} = \frac{t'_\mathrm{dyn}}{k}$$

(also tested: power-law decay)

Constraints to steepen the synchrotron slope without decreasing the radiative efficiency:

$$t'_\mathrm{syn}(\Gamma_\mathrm{m}) \ll \tau_\mathrm{B} \ll t'_\mathrm{syn}(\Gamma_\mathrm{c}) = t'_\mathrm{dyn}$$



Daigne & Bosnjak in preparation

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Decay k = 10
Decay k =100

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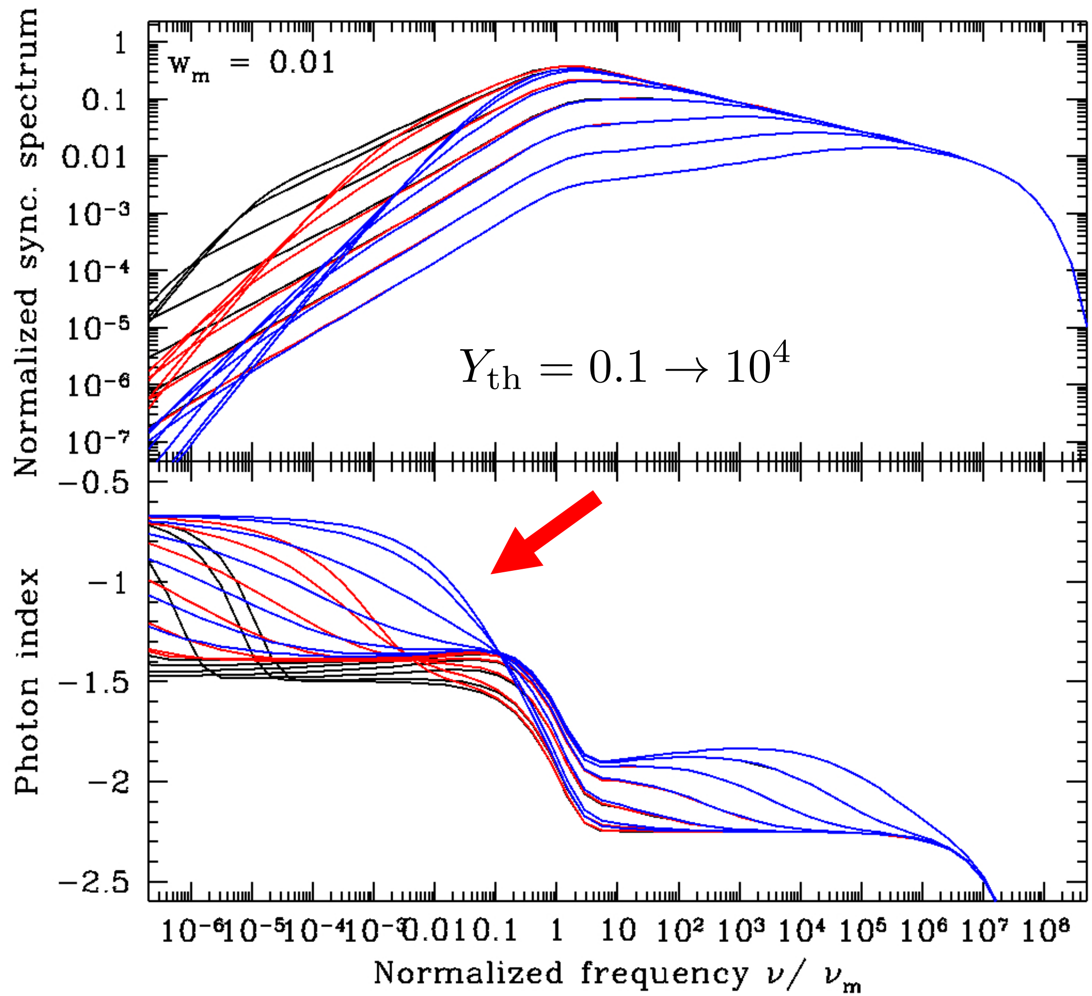

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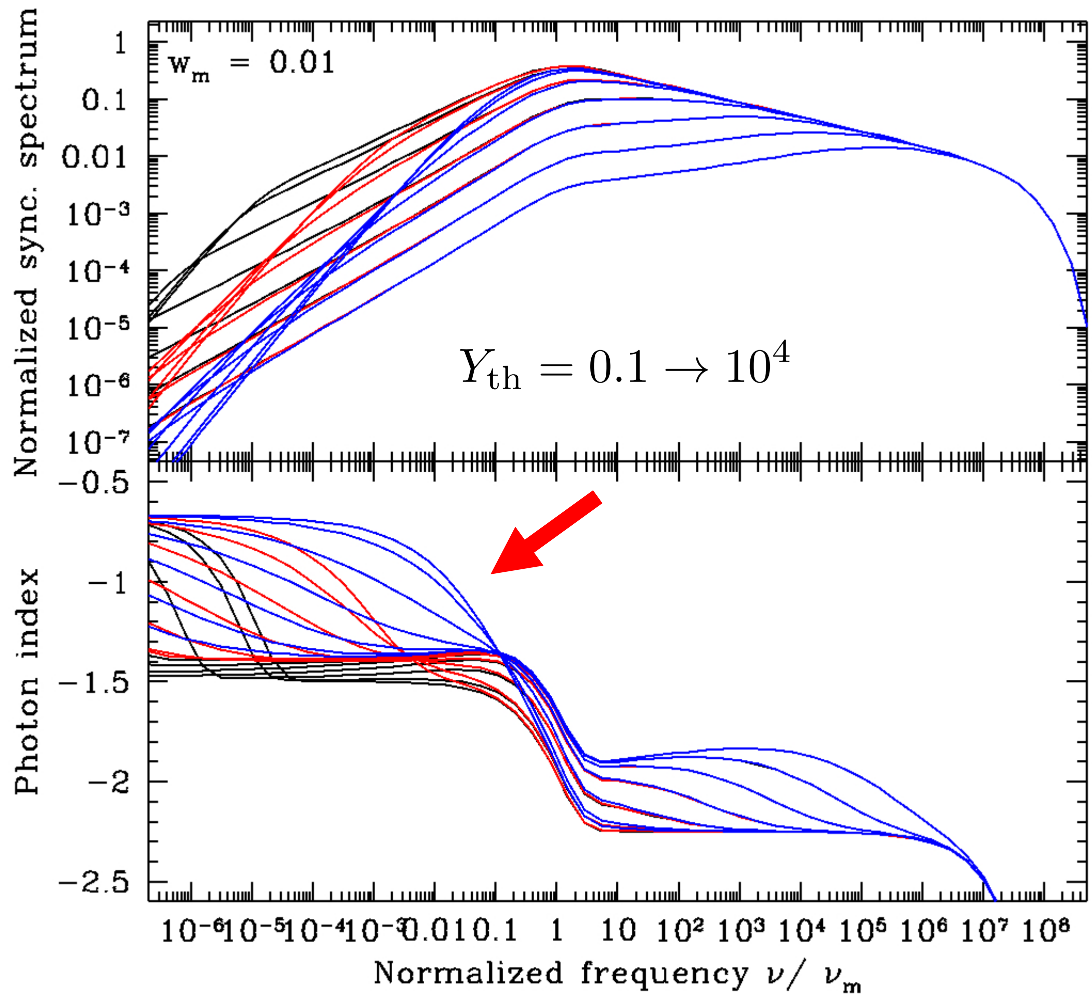
The low-energy slope α=-2/3 is easily recovered.

(natural marginally fast cooling)



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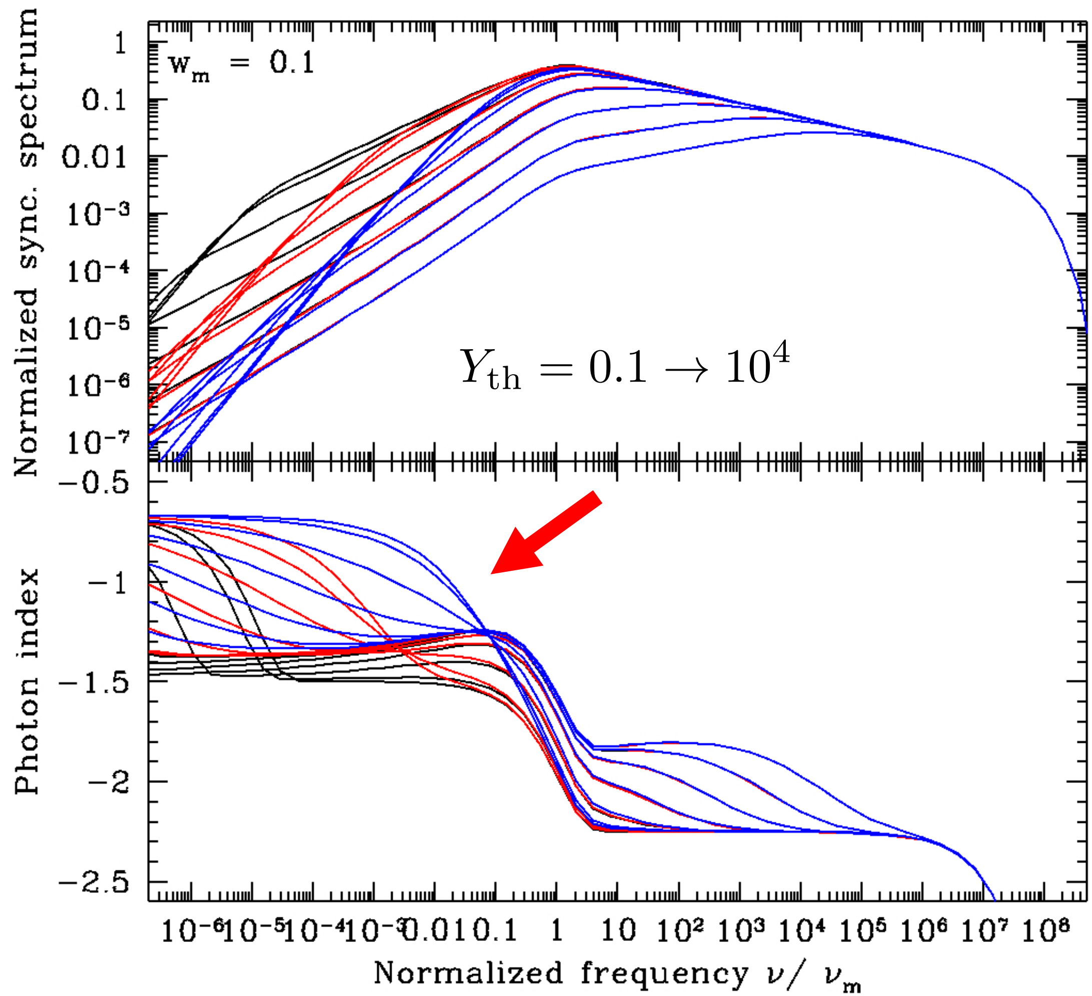

The low-energy slope α=-2/3 is easily recovered.

(natural marginally fast cooling)

Daigne & Bosnjak in preparation

Fast cooling synchrotron spectrum

No decay
Decay k = 10
Decay k =100

Effect of B decay

(e.g. Keshet et al. 11)

Here: exponential decay

$$B = B_0 e^{-t'/\tau_B}$$

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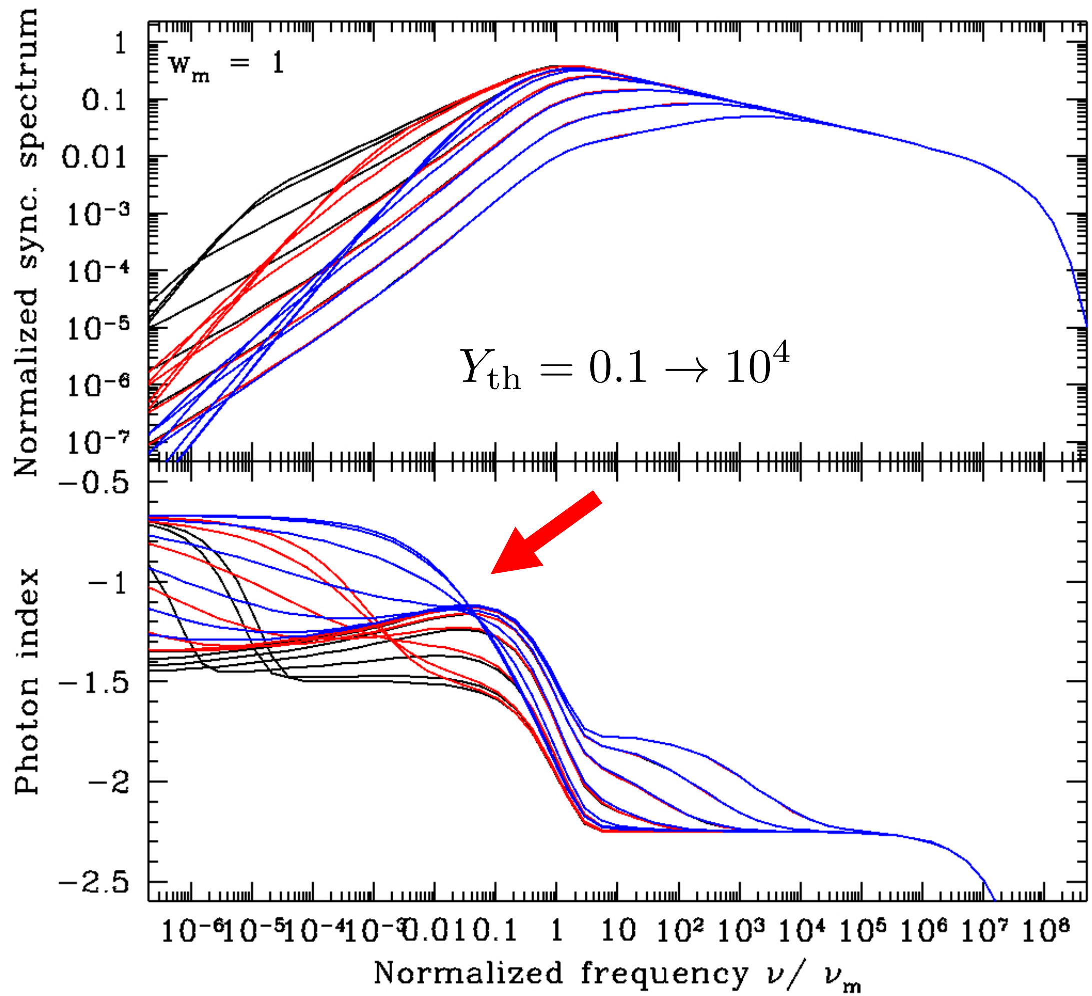

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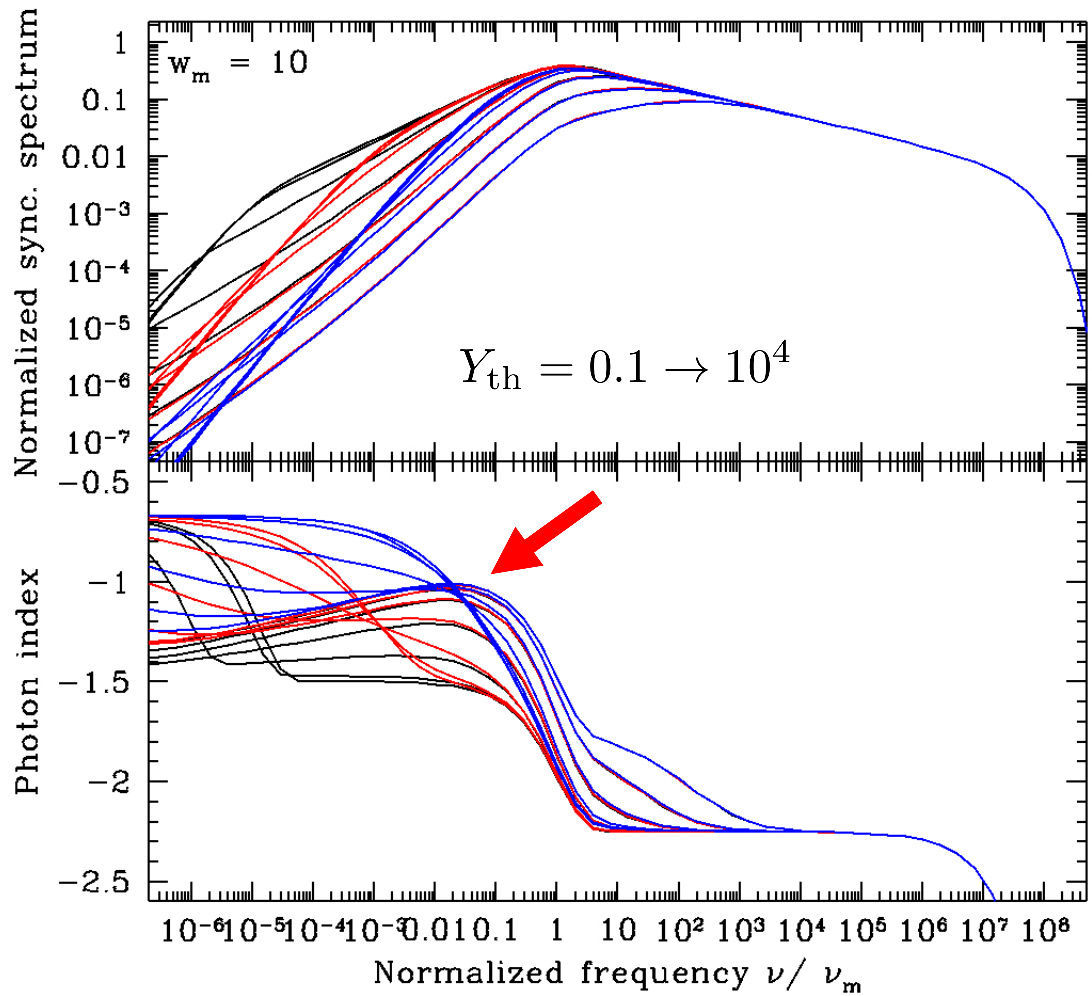

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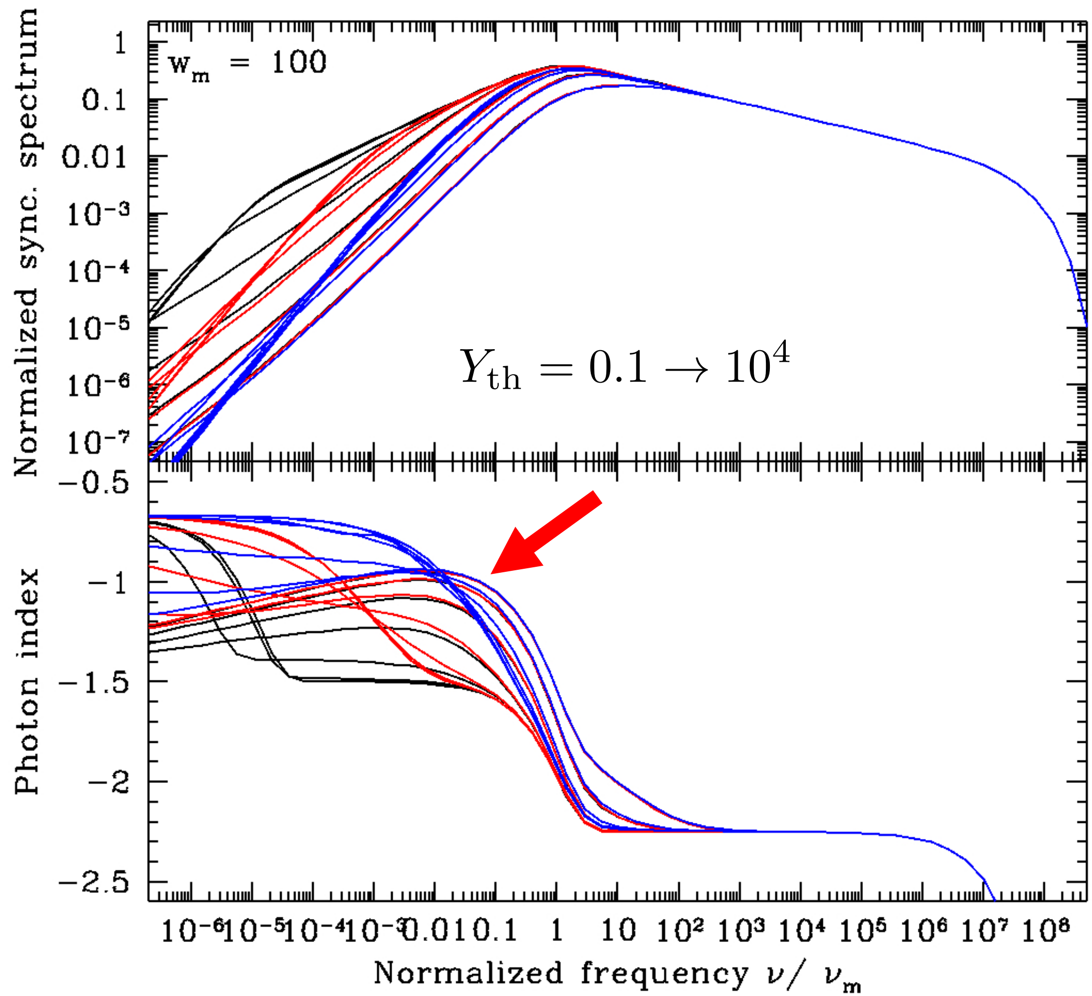

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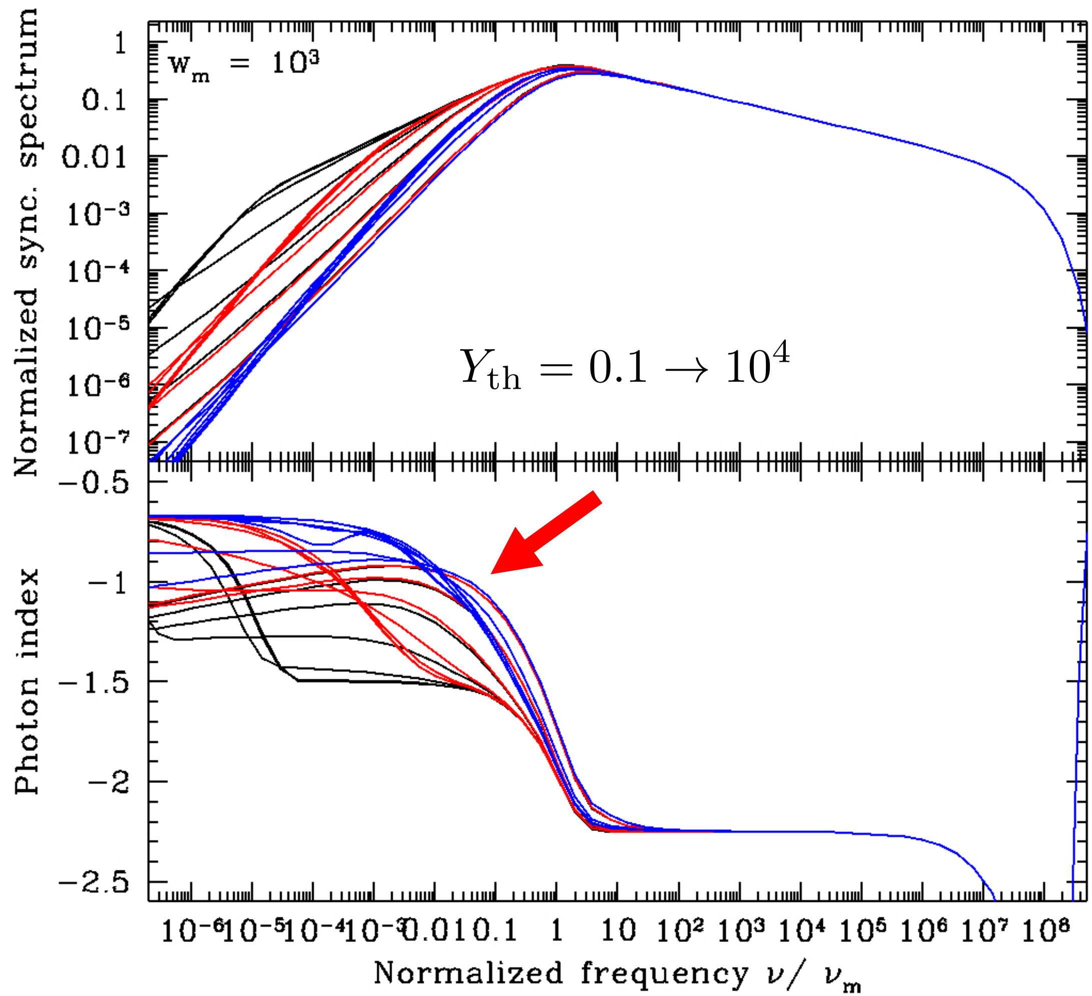

Daigne & Bosnjak in preparation

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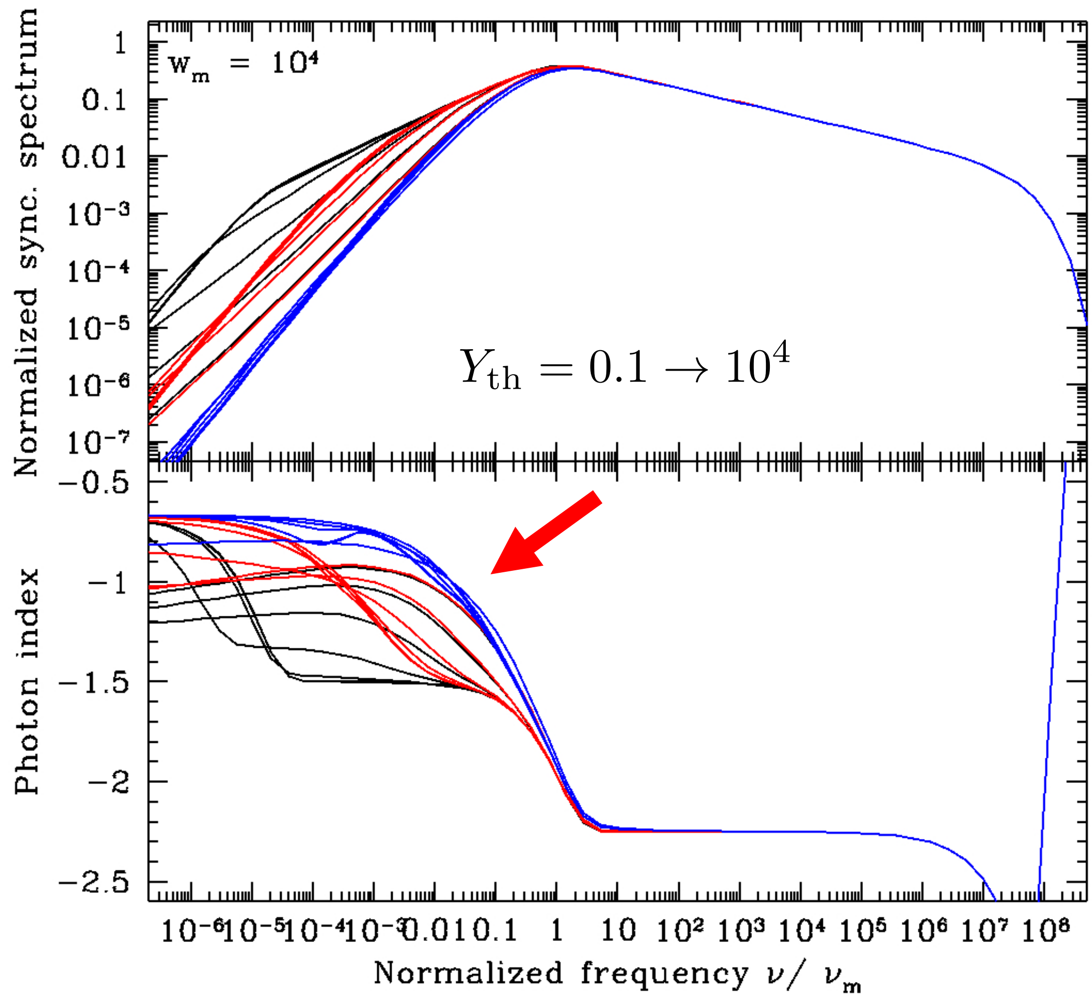


The low-energy slope α=-2/3 is easily recovered.

(natural marginally fast cooling)

Under investigation: high-energy emission? Spectral evolution?

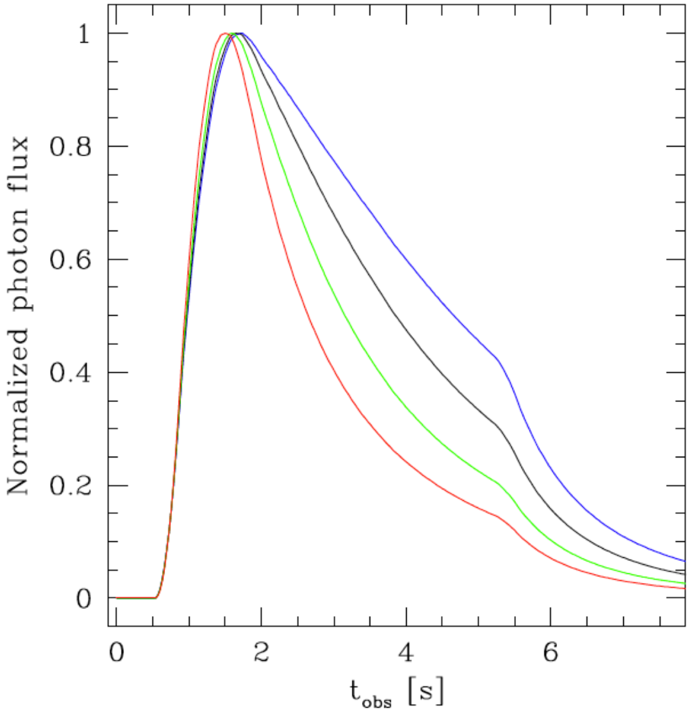
Daigne & Bosnjak in preparation

Internal Shocks: Results

Lighcurves – Spectrum – Spectral Evolution

Spectral evolution

Example of a simulated GRB pulse produced by internal shocks
(full simulation: dynamics+radiation)

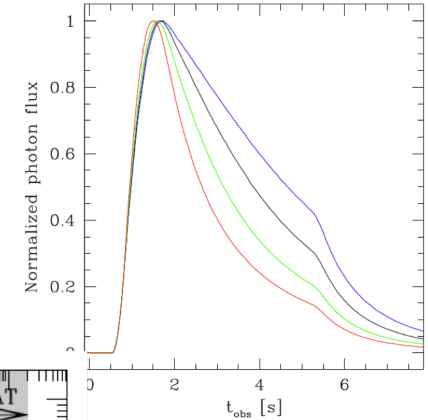


Light curve in BATSE range :
channels 1 (blue) to 4 (red)

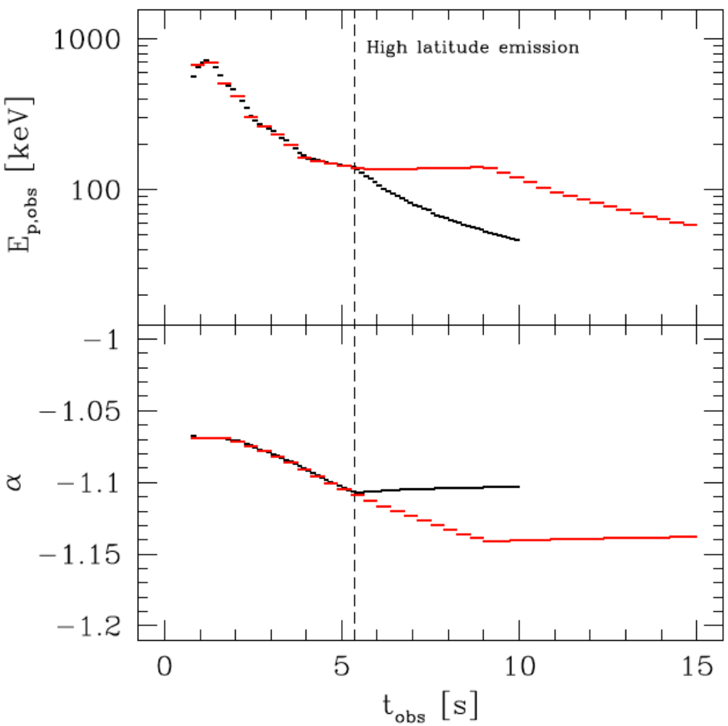
Bosnjak & Daigne 2014

Spectral evolution

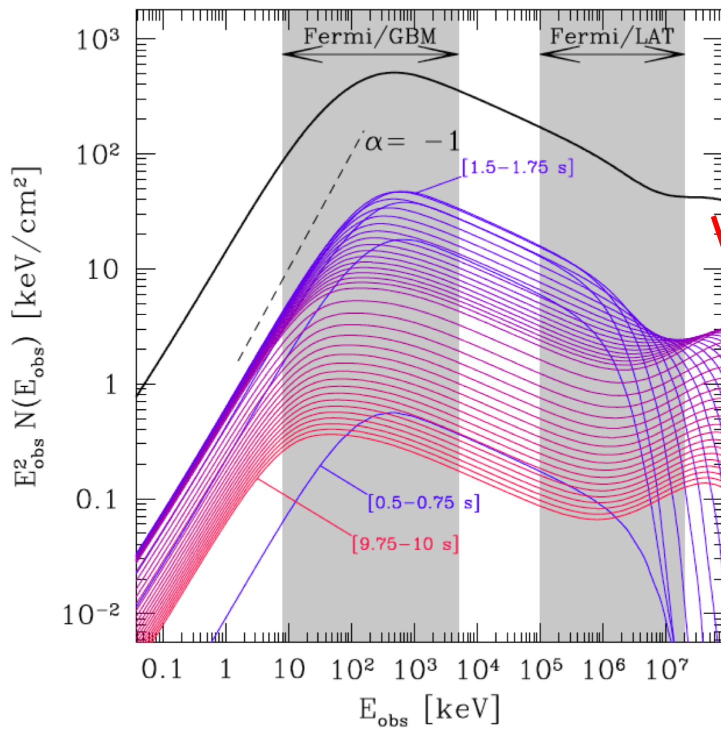
Example of a simulated GRB pulse produced by internal shocks
(full simulation: dynamics+radiation)



Evolution of E_{peak} and α



Time-evolving spectrum

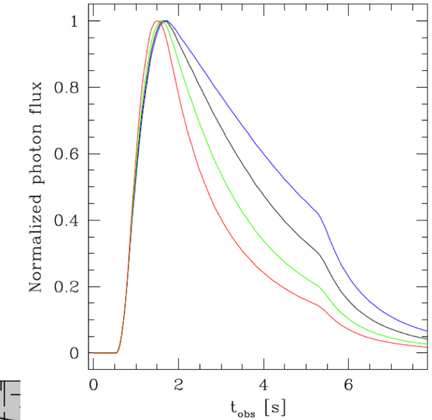


Extra component

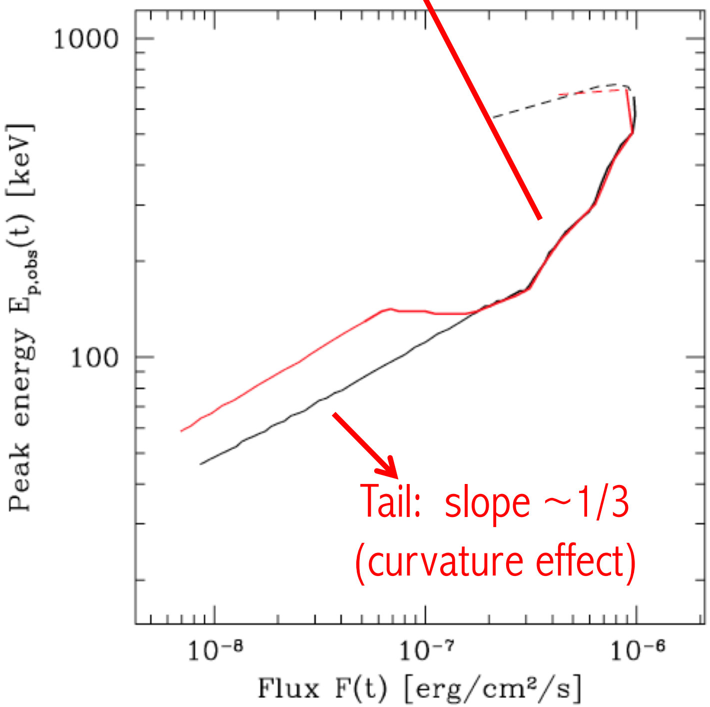
Bosnjak & Daigne 2014

Spectral evolution

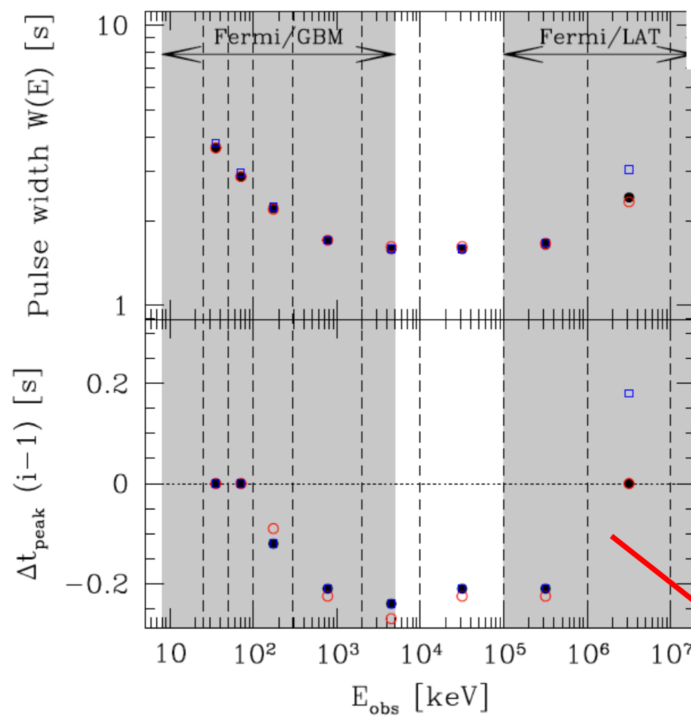
Example of a simulated GRB pulse produced by internal shocks
(full simulation: dynamics+radiation)



Slope ~1-1.5 fixed by shock propagation



Tail: slope ~1/3
(curvature effect)



$$W(E) \propto E^{-a}$$

$$a \simeq 0.2 - 0.3$$

Hardness-Intensity Correlation

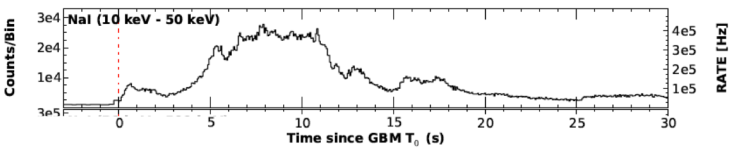
Pulse width and time lags

Delayed onset ? $\gamma\gamma$?
(Hascoet et al. 2012)

Bosnjak & Daigne 2014

Spectral evolution

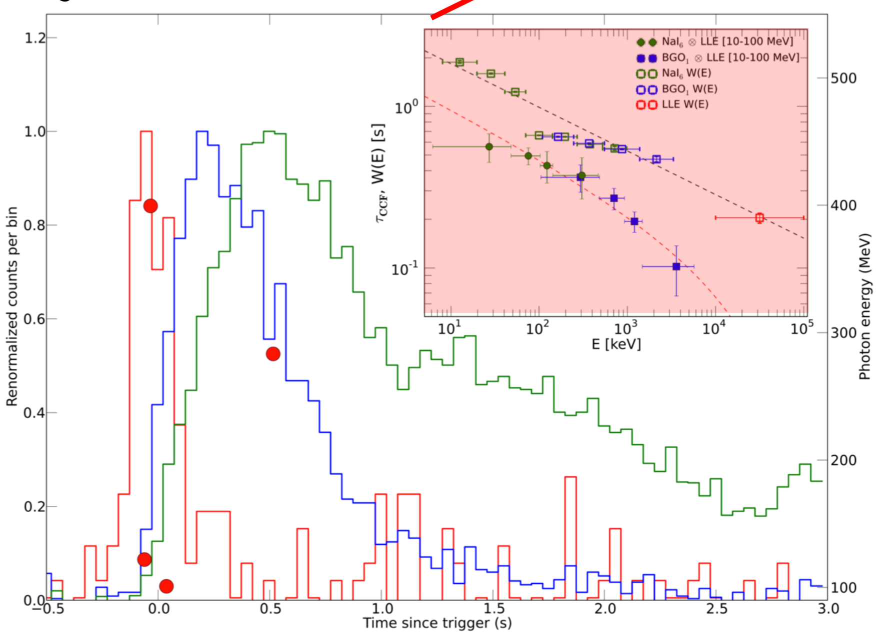
GRB 130427A

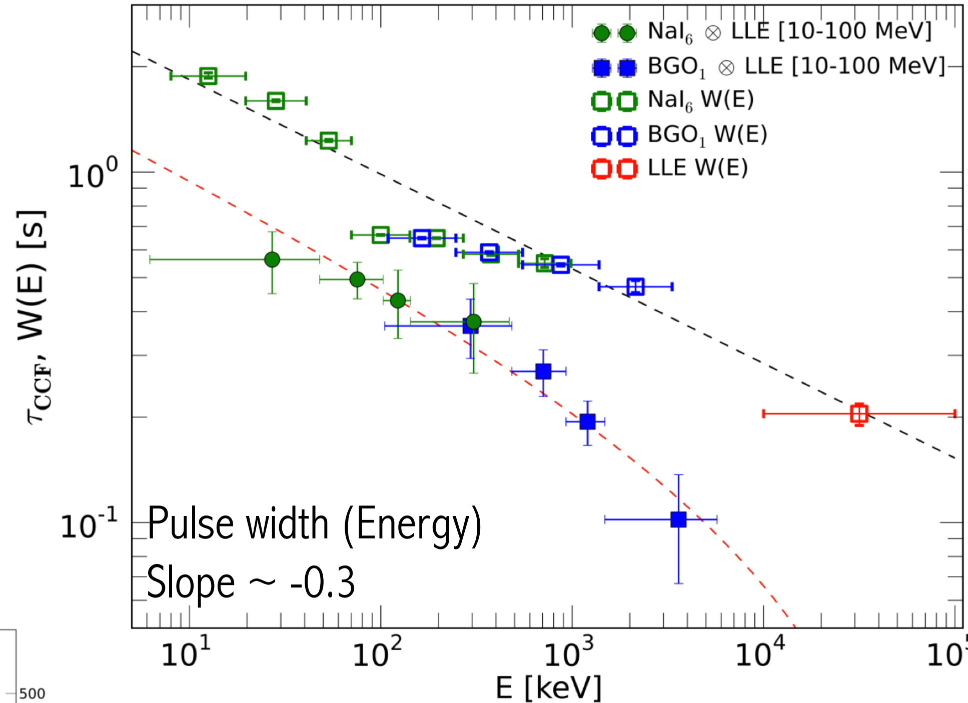


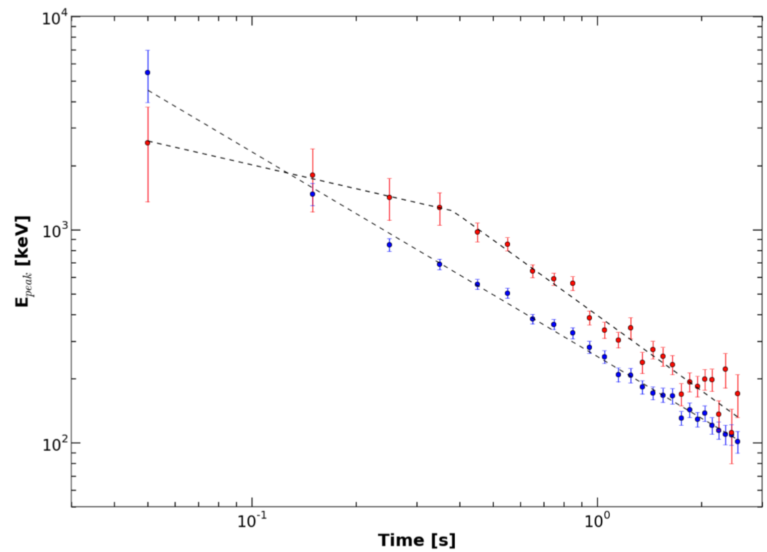
The first 3 s

zoom

Time lags



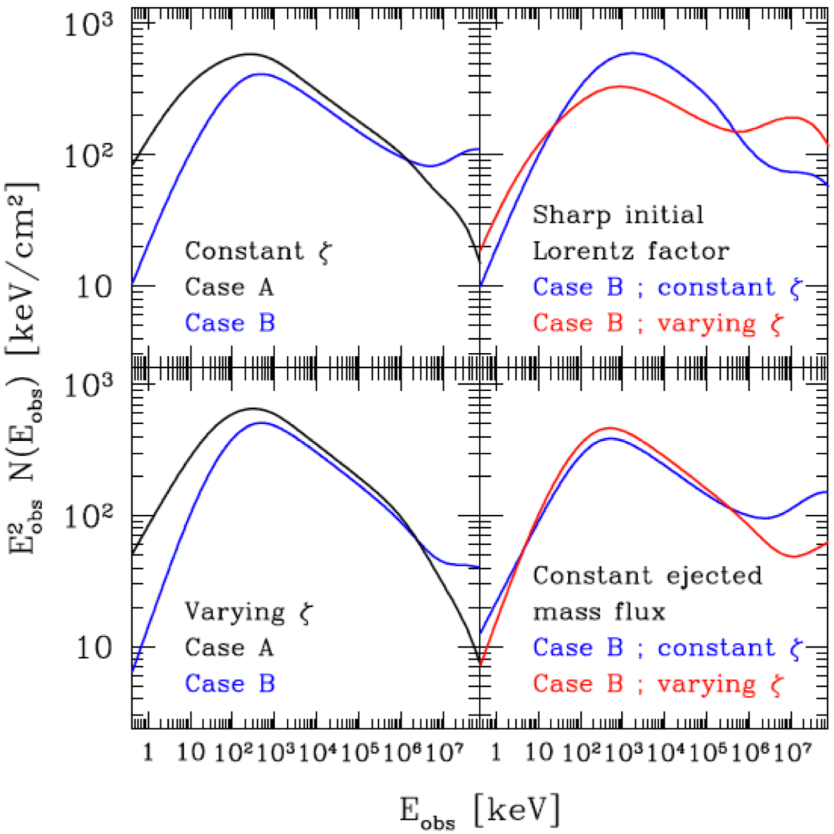


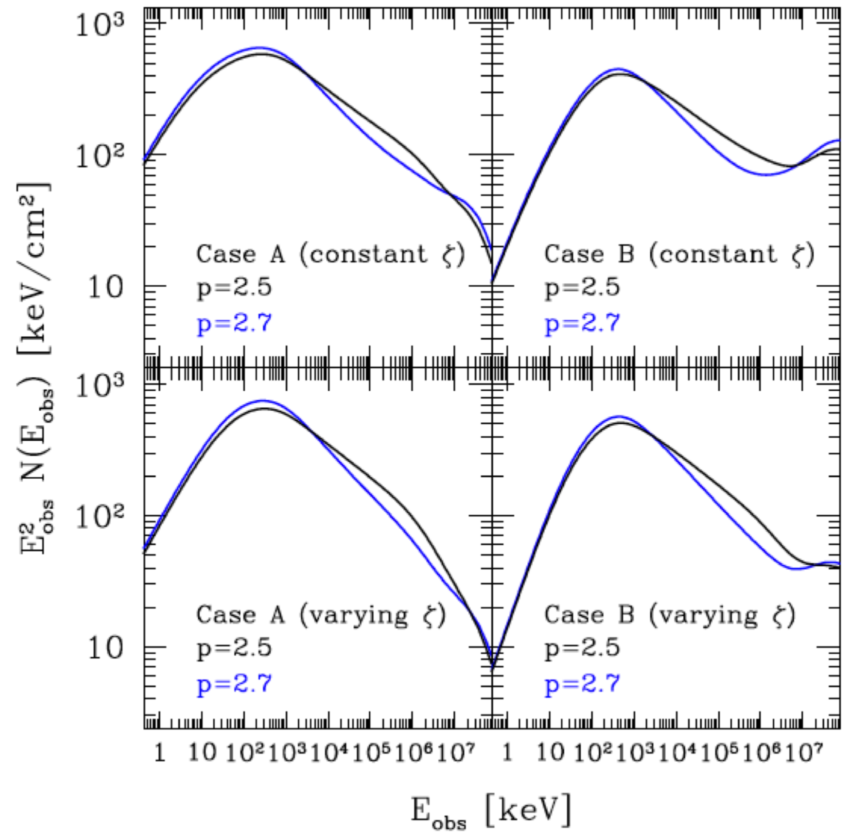


Preece et a.l. 2014

Not shown: hardness-intensity correlation slope 1.4

Prompt GeV emission from internal shocks





Comparison with 2nd LAT GRB catalog:
work in progress

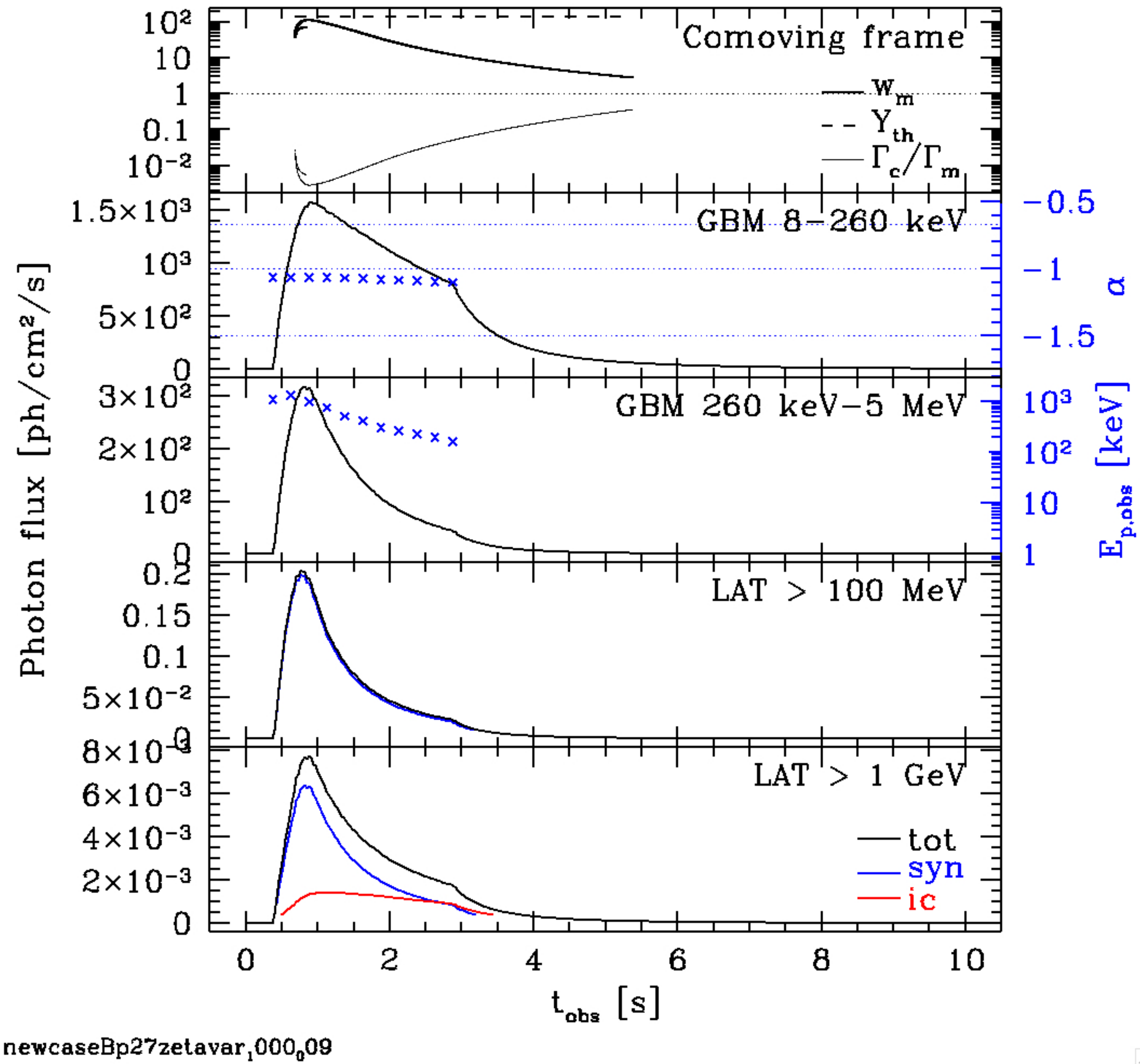
Bosnjak & Daigne 2014 ; see also Asano & Meszaros.

Low-energy slope: effect of B decay

Example of a simulated GRB
(full simulation:
dynamics+radiation)

Case B
of Bosnjak & Daigne 2014
High w_m, Y_{th}
Slope ~ -1.1

No B decay



Daigne & Bosnjak in preparation

Low-energy slope: effect of B decay

Example of a simulated GRB
(full simulation:
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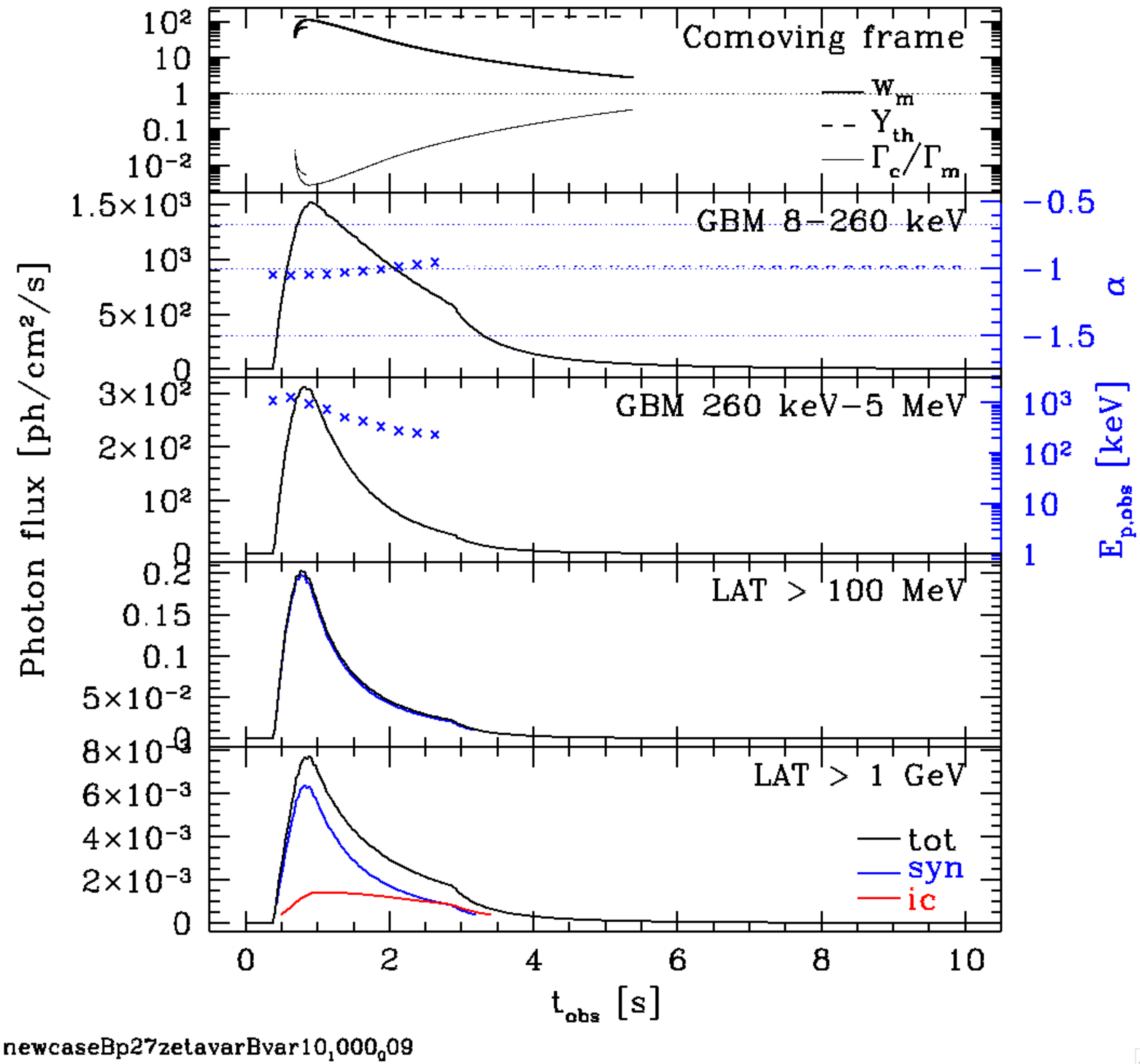
Case B
of Bosnjak & Daigne 2014
High w_m, Y_{th}
Slope ~ -1.1

B decay
$\tau_B/t'_{dyn} = 1/10$



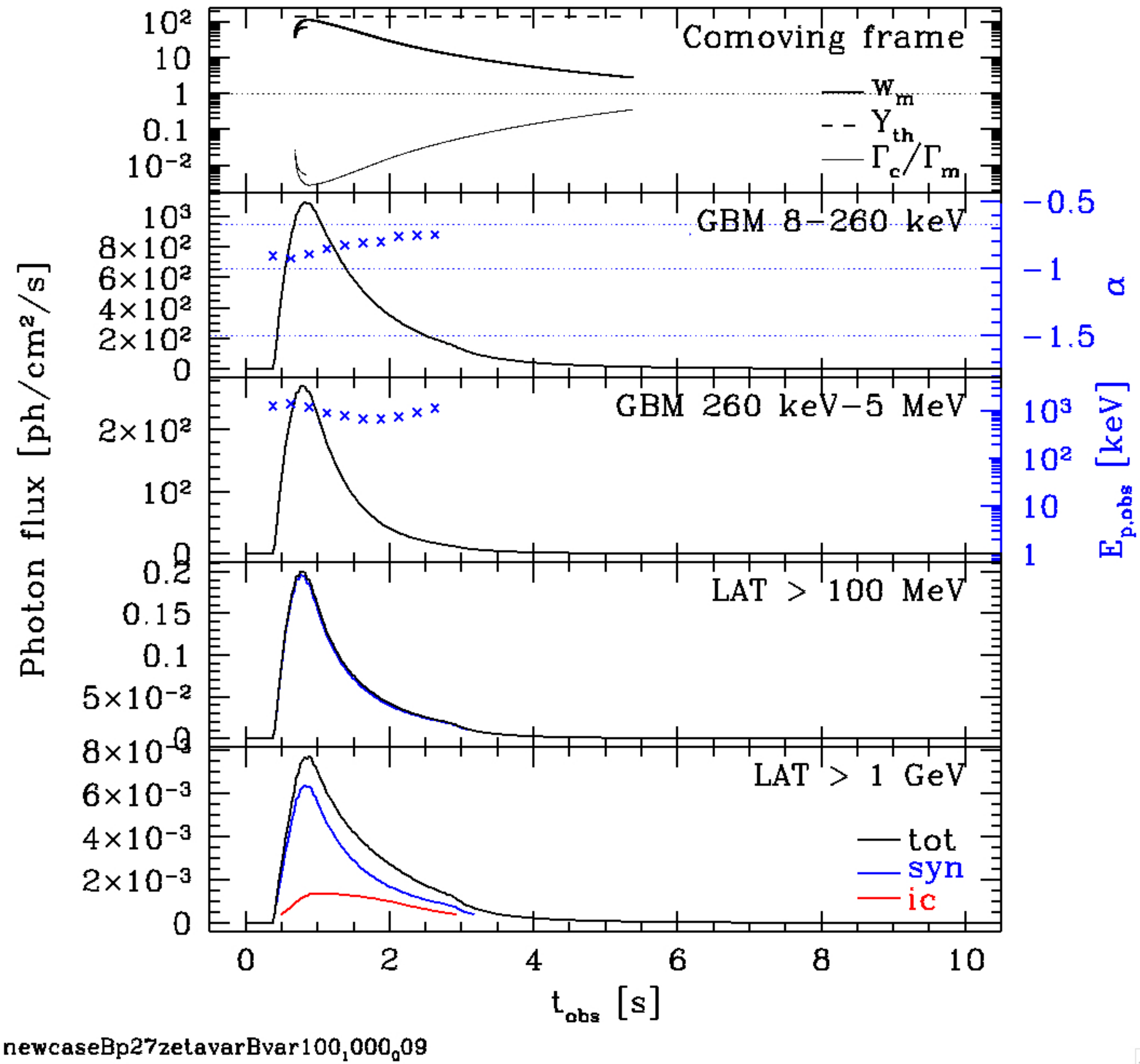
<u>Daigne</u> & Bosnjak in preparation

Low-energy slope: effect of B decay

Example of a simulated GRB
(full simulation:
dynamics+radiation)

Case B
of Bosnjak & Daigne 2014
High w_m, Y_{th}
Slope ~ -1.1

B decay
$\tau_B/t'_{dyn} = 1/100$
Slope ~ -0.9



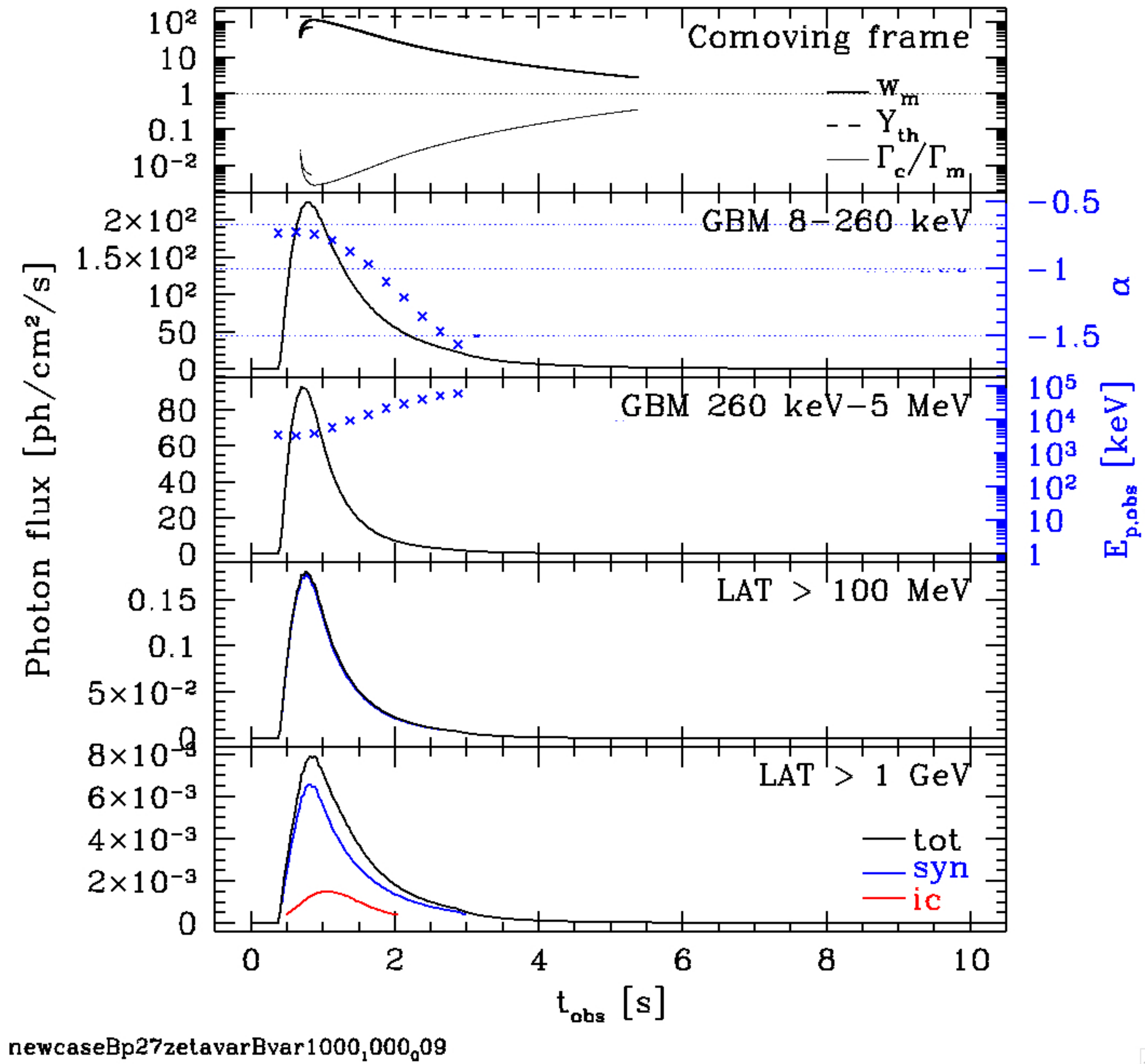
Daigne & Bosnjak in preparation

Low-energy slope: effect of B decay

Example of a simulated GRB (full simulation: dynamics+radiation)

Case B
of Bosnjak & Daigne 2014
High w_m, Y_{th}
Slope ~ -1.1

B decay
$\tau_B/t'_{dyn} = 1/1000$
Slope ~ -0.7



<u>Daigne</u> & Bosnjak in preparation

The case of short GRBs

Short GRBs emit
at higher energies
→ MeV domain

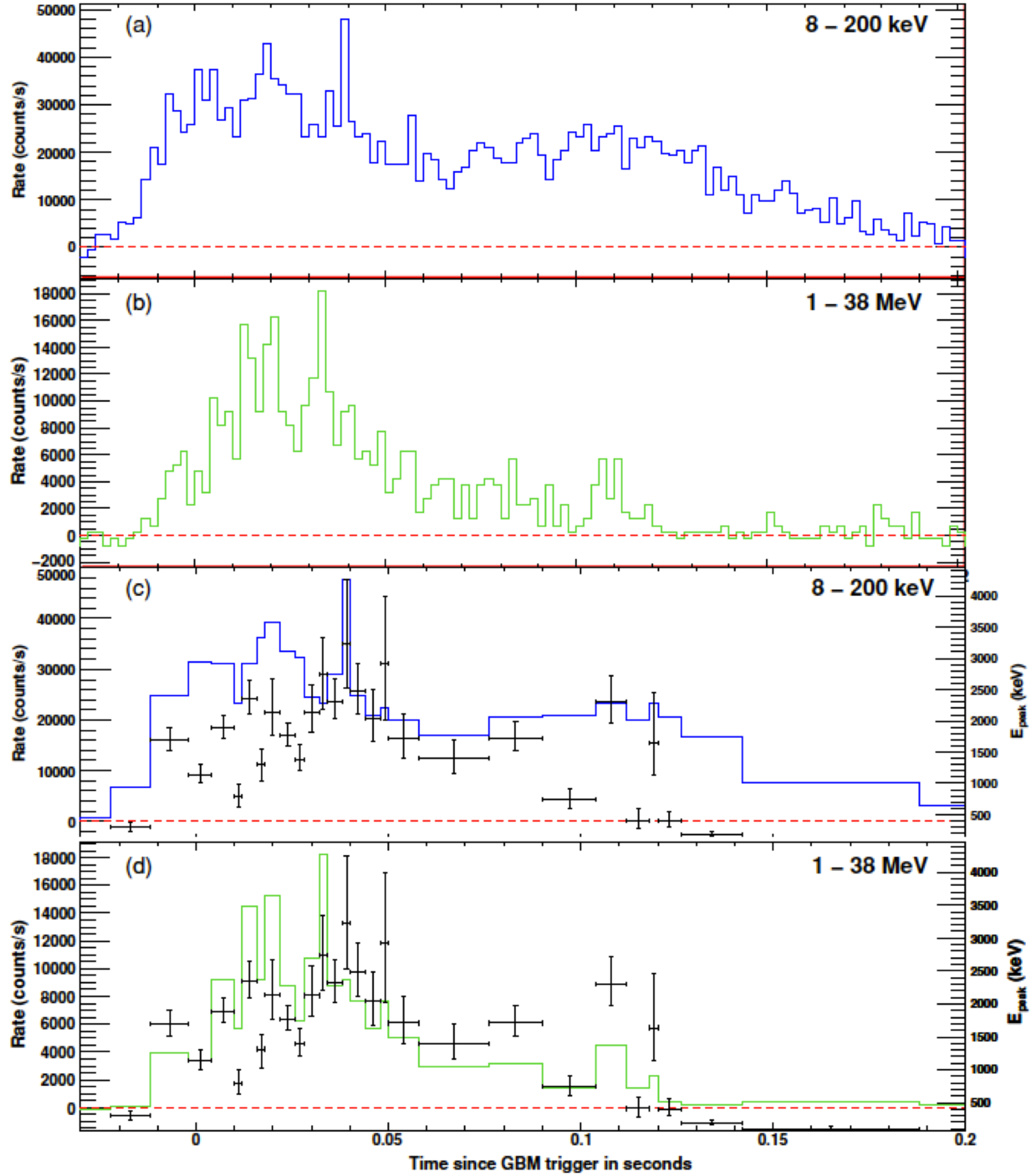


Figure 1. Light curves of GRB 090227B in two energy bands (panel (a): 8 keV to 200 keV, NaI detectors) and (panel (b): 1 MeV to 38 MeV, BGO detectors) with 2 ms time resolution. The count rates are background subtracted. Two bottom panels: the same light curves with variable time bins (histograms), optimized for time-resolved spectroscopy. The Band function peak energy, E_{peak}, is plotted over the light curve for each time interval.

GRB 090227B
(*Fermi*/GBM)
duration ~ 0.15 s

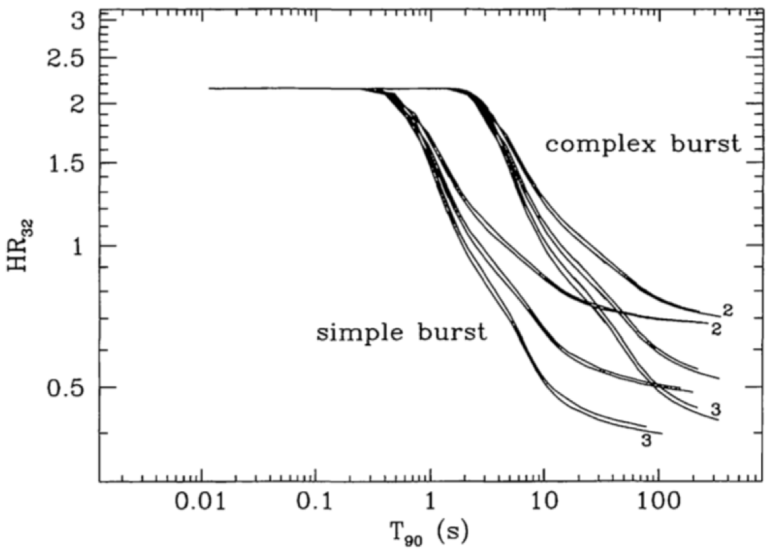
3 MeV

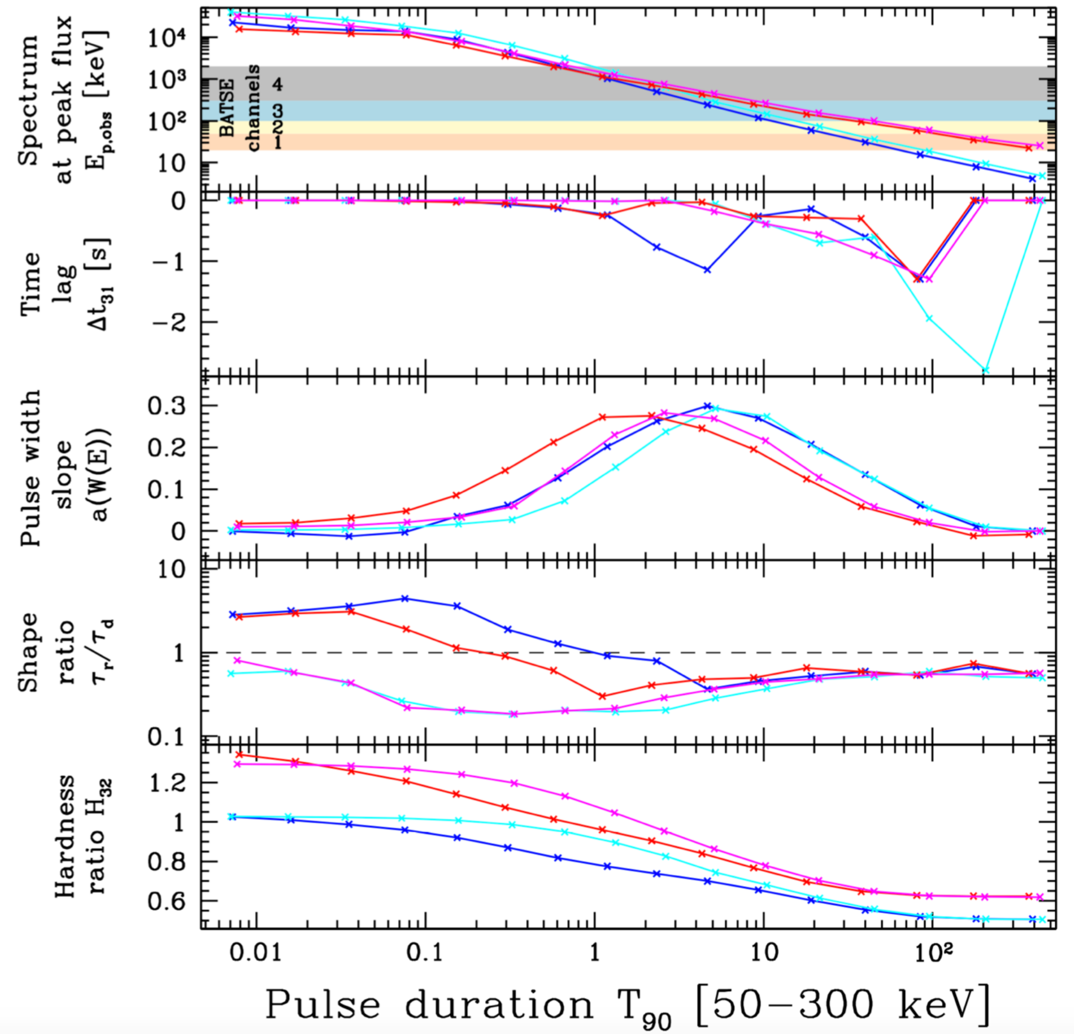
1 MeV

Guiriec et al. 2010

The case of short GRBs

- Model a pulse with internal shocks
- Vary only the duration of the relativistic ejection (L=cst)
- Main properties of the short GRB population emerge (harder, no lags, …)





Daigne & Mochkovitch 1998

Bosnjak & Daigne 2014

Recent results – Work in progress

- Comparison to GBM spectra: a new fitting procedure
  (Yassine, Piron, Longo, Daigne & Mochkovitch, submitted to A&A)

- Effect of B decay: a natural way to reach the marginally fast cooling regime
  (Daigne & Bosnjak in preparation)

- Distribution of internal shock parameters (population model):
  work in progress with Z. Bosnjak & J. Palmerio

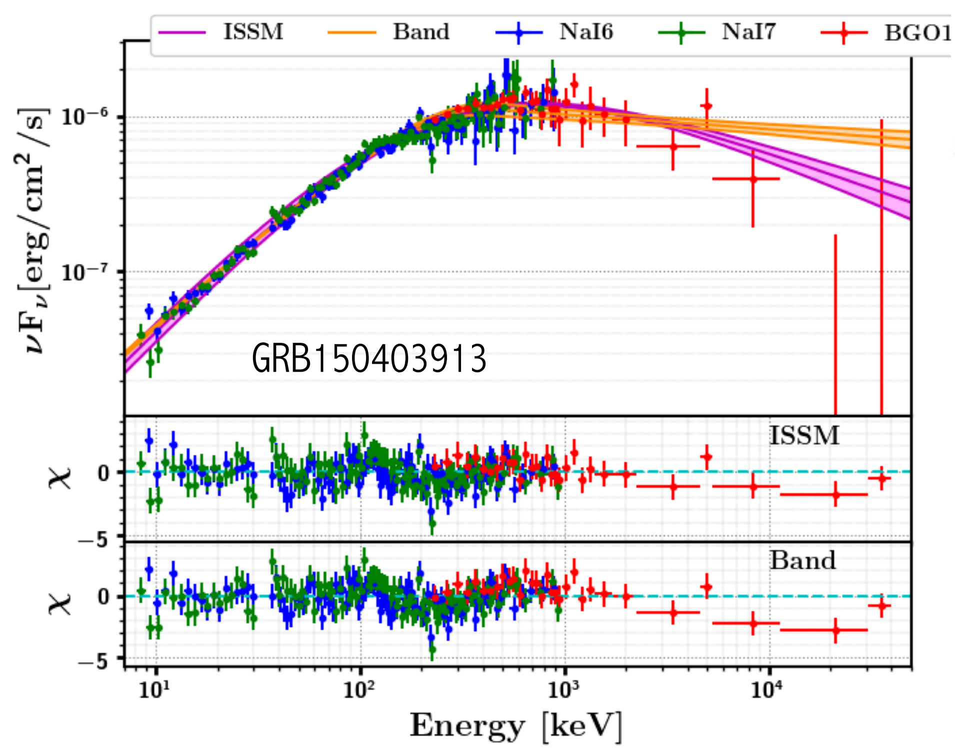
- Predictions at high and very high energy (CTA): see Z. Bosnjak's talk

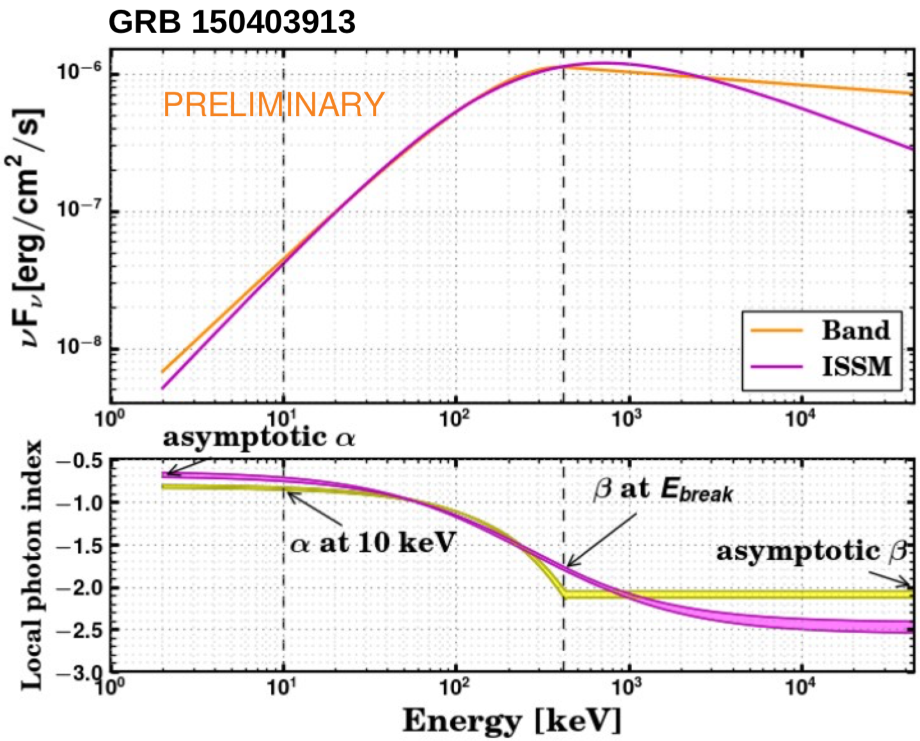
ISSM Spectral Model

- Alternative to Band function
- Same number of parameters (4)
- Continuous curvature

$$\Gamma(E) = \alpha + (\beta - \alpha)\,\frac{\frac{E}{E_{\rm p}}}{\frac{E}{E_{\rm p}} - \frac{2+\beta}{2+\alpha}}$$

- Fits well synthetic spectra obtained with the internal shock model
- **Fits also well observed spectra!**





ISSM Spectral Model

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- Same number of parameters (4)
- Continuous curvature

$$\Gamma(E) = \alpha + (\beta - \alpha)\,\frac{E}{E - E_{\mathrm{p}}\,\frac{2+\beta}{2+\alpha}}$$

- Fits well synthetic spectra obtained with the internal shock model

- Test: 74 Fermi/GBM GRBs with a high fluence – Comparison Band vs ISSM
  ISSM is a good model for 60/74 (81%)
  Band is a good model for 44/74 (59%)

- ISSM leads to larger peak energy, broader spectra around the peak.
  It looks narrower than Band over a wide energy range.

- **Asymptotic slopes are different but low-energy slope remain steep.**

- **Band imposes a shape which is may be not real: be careful when comparing model and observations**

ISSM Spectral Model

- Next step: fit directly GBM bursts with the internal shock model (under discussion with LUPM's group)

Summary

Summary

- Three main mechanisms are proposed for the GRB prompt emission
(dissipative photosphere – internal shocks – reconnection)

- The internal shock model can be computed in details, allowing a careful comparison with observations

- Many nice properties but it is not clear if the precise shape of the observed spectrum can be reproduced (but it is not clear if this shape is well measured with current observations)

- Important questions related to the underlying microphysics
Efficient acceleration in mildly relativistic shocks?
Magnetic field: intensity? Decay?

- Distinguishing between the proposed mechanisms?

- GRB/GW170817: a different mechanism for the GRB?
Jet structure: consequences?

How relativistic are GRB outflows? Constraints on the emission radius

Relativistic motion:

-Direct (in a few cases): apparent super-luminal motion

-Indirect: necessary to avoid a strong $\gamma\gamma$ annihilation

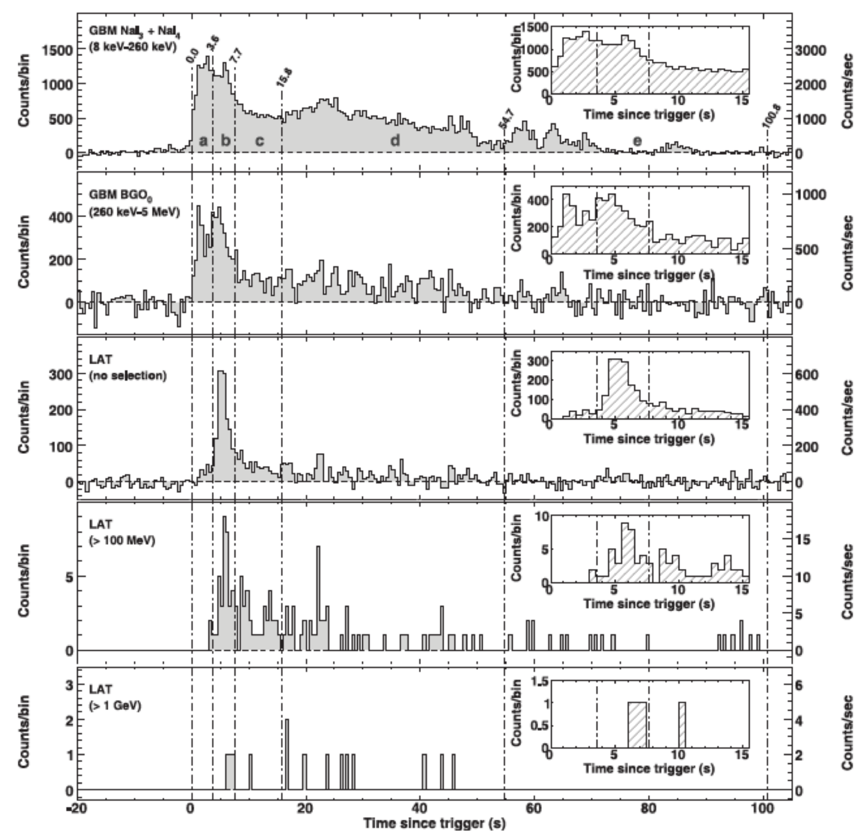
-Other indirect methods: rise of the afterglow, etc.

How relativistic are GRB outflows?

Pre-Fermi (MeV range) : $\Gamma_{min} \sim$ 100-300

GeV detection by Fermi: stricter Lorentz factor constraints

- GRB 080916C: $\Gamma_{min} \geq 887$ (Abdo et al. 09)
- GRB 090510: $\Gamma_{min} \geq 1200$ (Ackerman et al. 10)

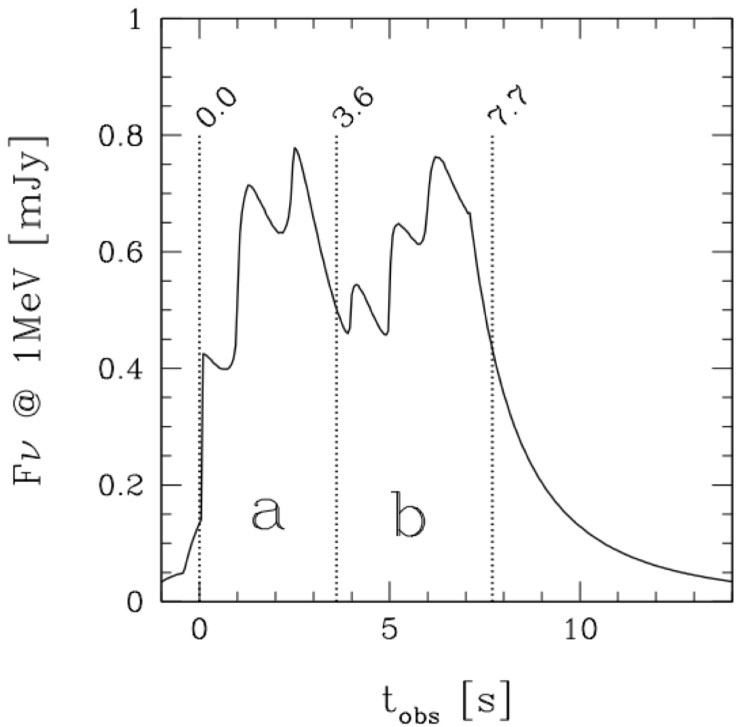


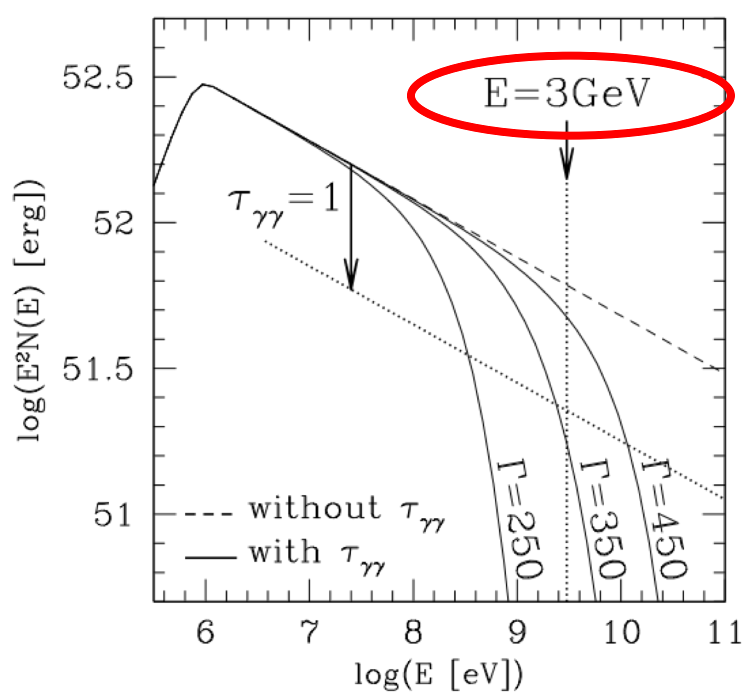
How relativistic are GRB outflows?

Detailed calculation: space/time/direction-dependent radiation field

the estimate of Γ_{min} is reduced by a factor ~ 2-3

(see Granot et al. 2008; Hascoët, Daigne, Mochkovitch & Vennin 2012)



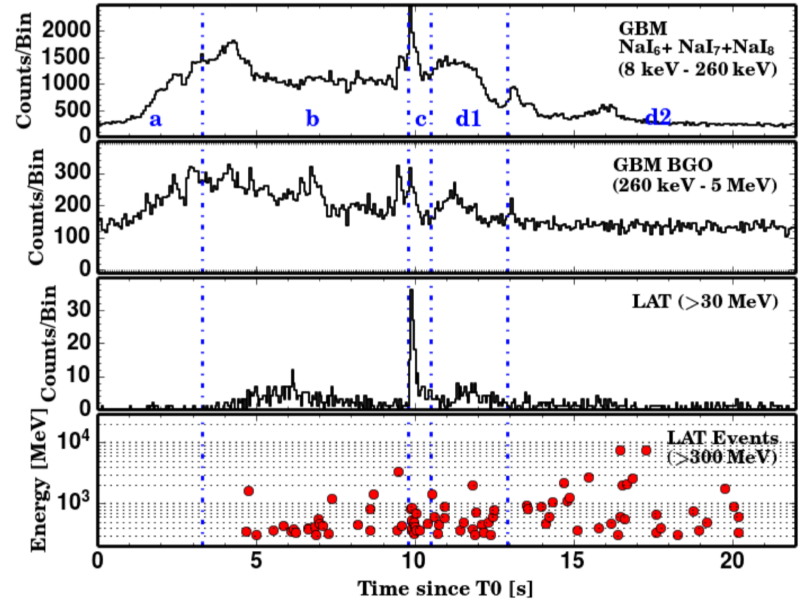


GRB 080916C : $\Gamma_{min} \sim 360$ (Hascoët, Daigne, Mochkovitch & Vennin, 2012)

instead of ~900 (Abdo et al. 2009)

First observation of the γγ cutoff ?

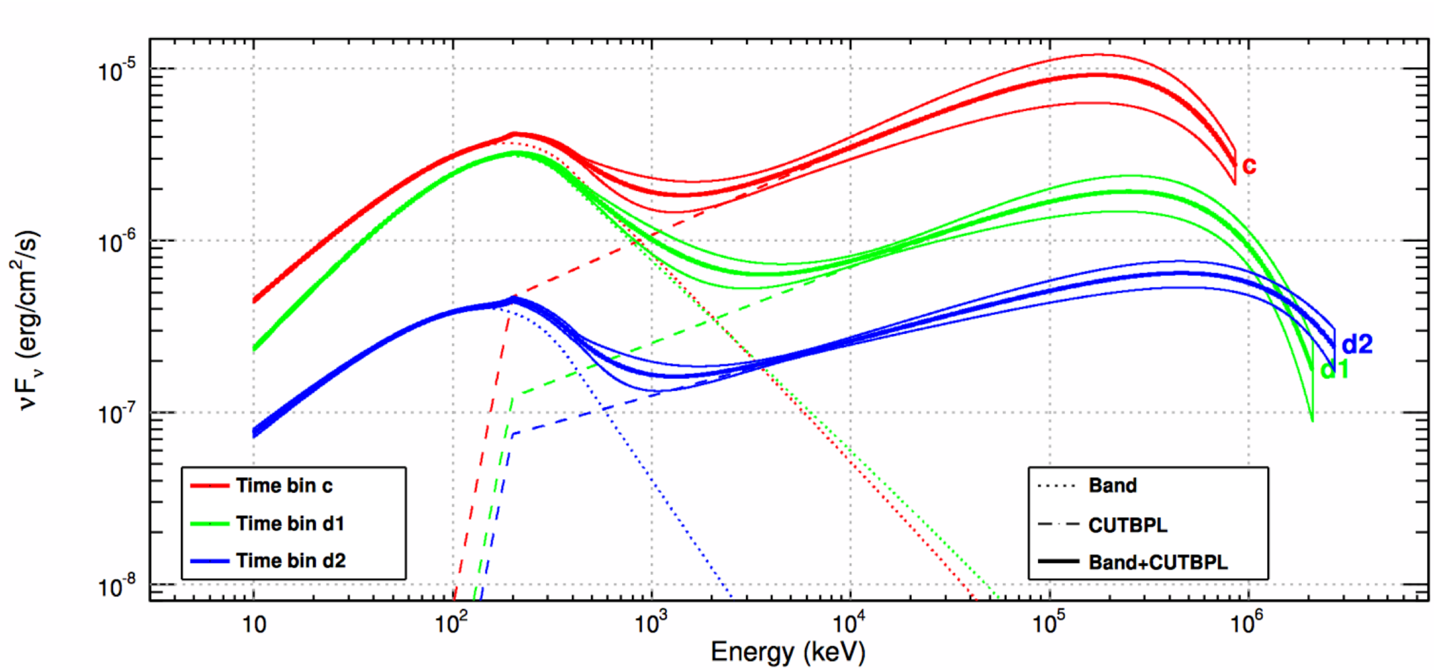
- GRB 090926A (Fermi-LAT):
  first observed cutoff at high-energy
  (Ackermann et al. 2011)



- New analysis and interpretation:

  - Path 8: 447 ⟶ 1088 evts in LAT (× 2.4)
  - cutoff is *better* detected, in *several* time bins

Yassine+17 [FD]



First observation of the $\gamma\gamma$ cutoff ?

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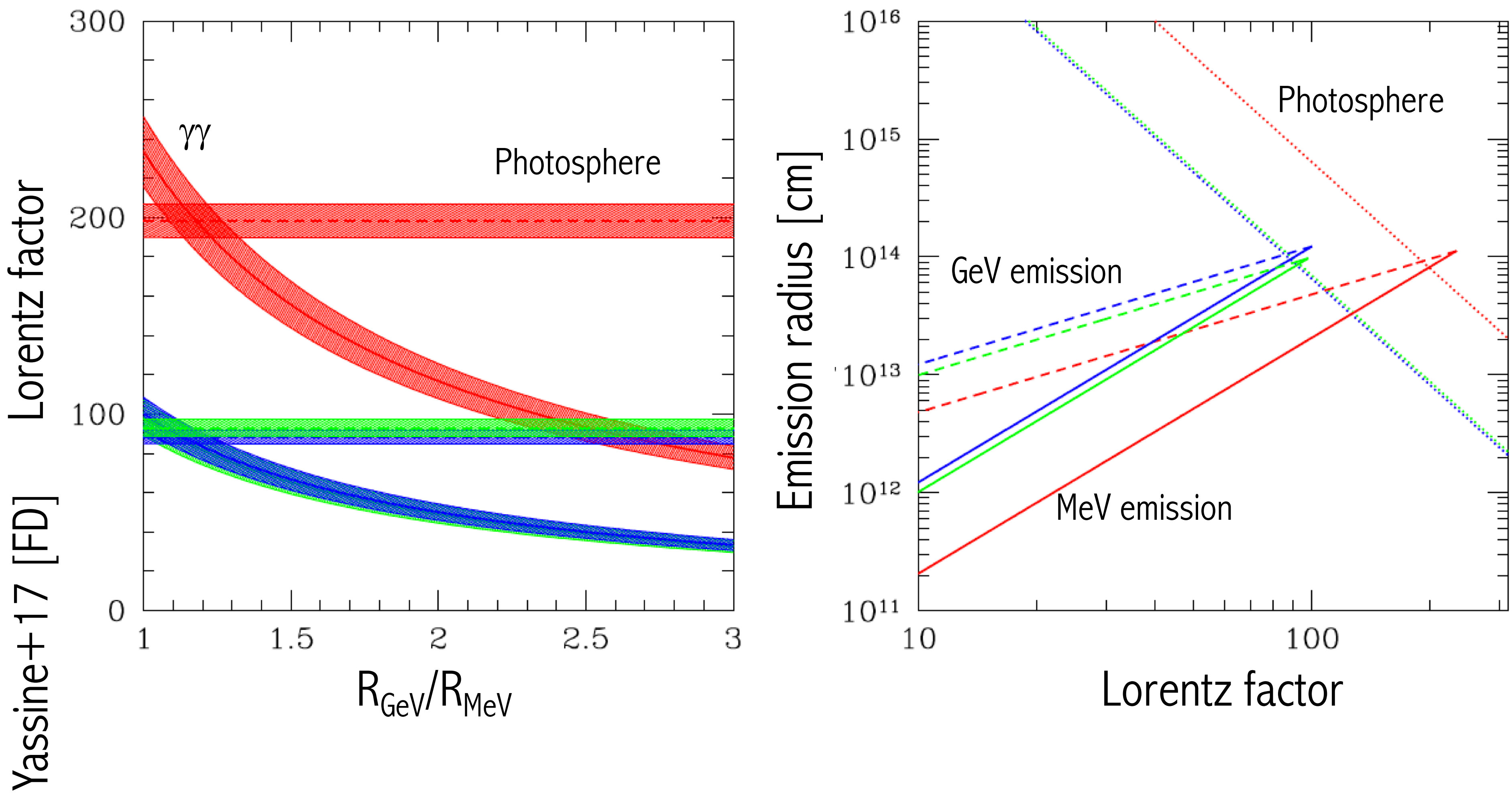
- New analysis and interpretation: cutoff detected in several bins, **strong constraint on Lorentz factor and emission radius**!

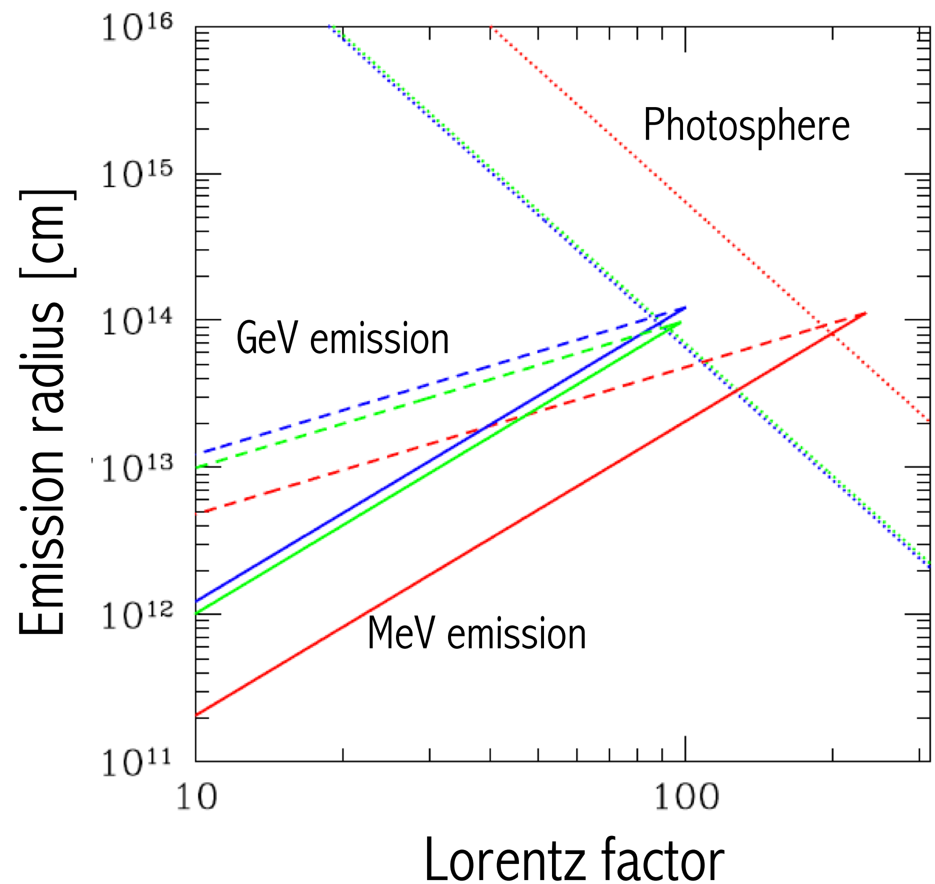


First observation of the $\gamma\gamma$ cutoff ?

- GRB 090926A (Fermi-LAT): first observed cutoff at high-energy (Ackermann et al. 2011)
- New analysis and interpretation: cutoff detected in several bins, **strong constraint on Lorentz factor and emission radius!**

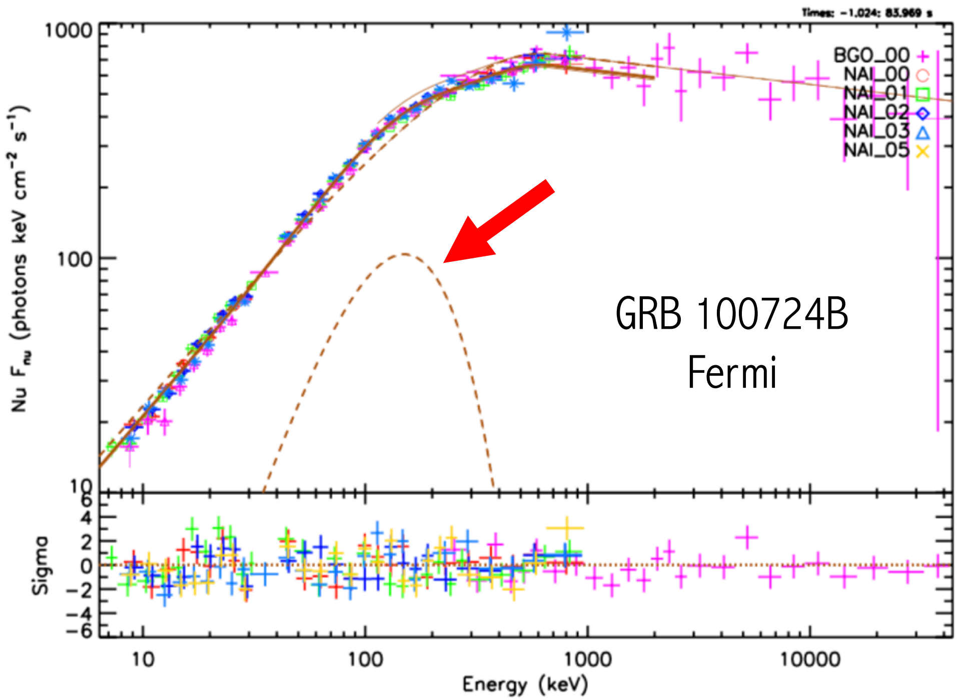
Lorentz factor ~ 230 to 100
Emission radius ~ 10^{14} cm
Photospheric radius ~5 10^{13} cm

Compatible with « standard scenario » (internal shocks/reconnection above the photosphere)



Yassine, Piron, Daigne & Mochkovitch, 2017

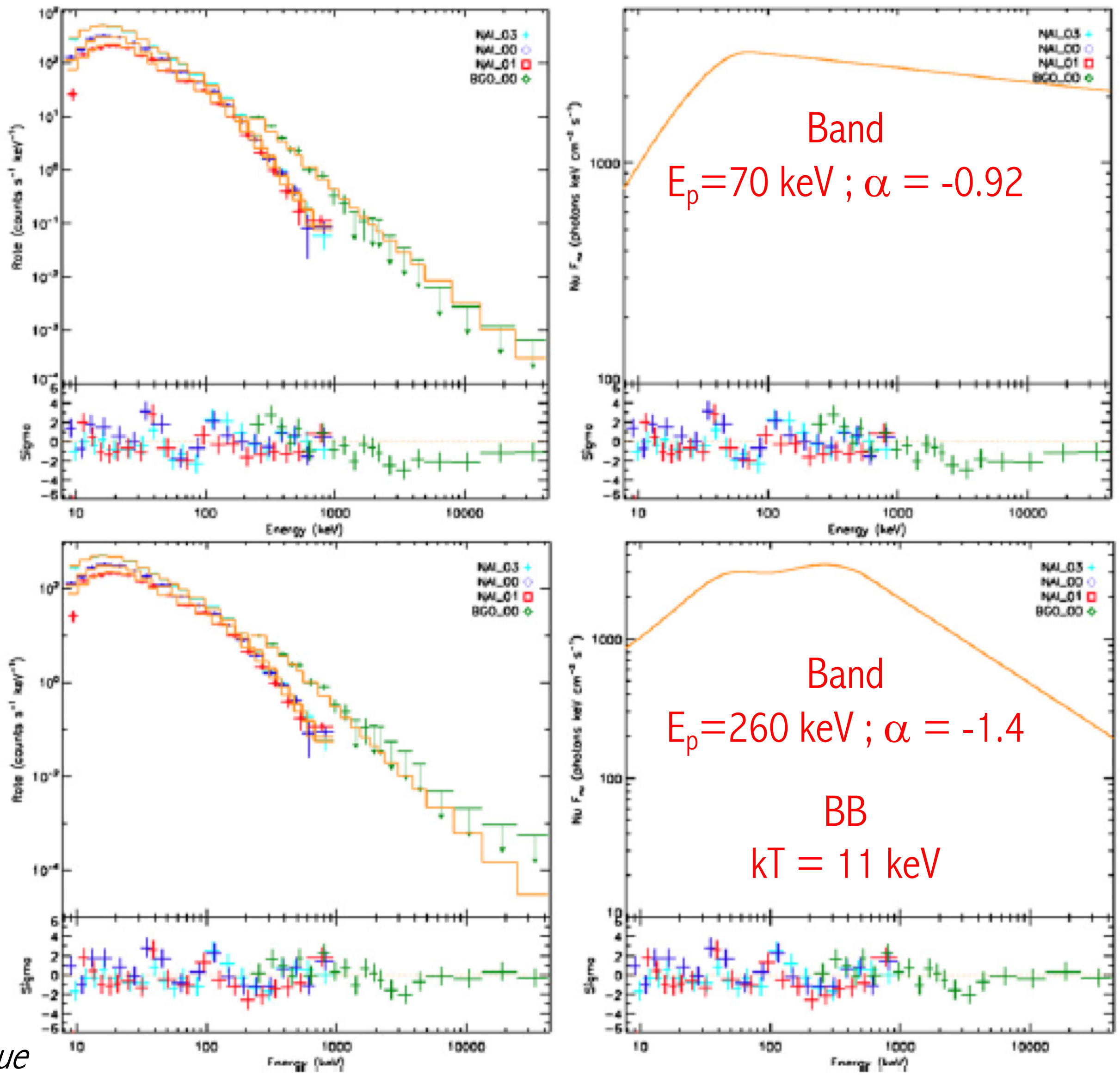
Magnetization in GRB outflows?
Constraints from quasi-thermal components



Guiriec et al. [FD] 2011

Weak quasi-thermal components in GRB spectra?

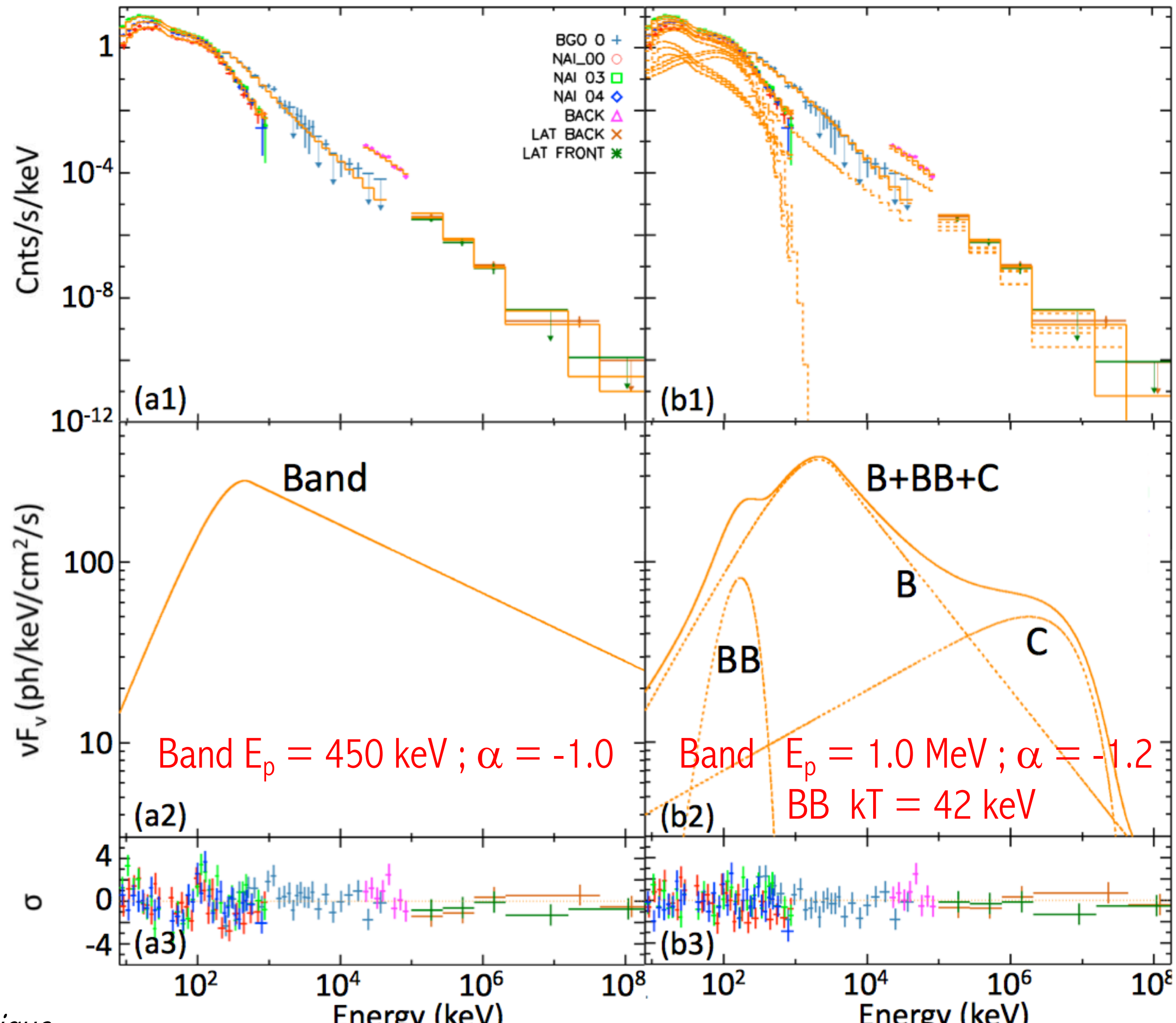
e.g. GRB 120323A (short GRB) Guiriec [FD] et al. 2013



Warning:
spectral analysis based
on forward folding technique

Weak quasi-thermal components in GRB spectra?

e.g. GRB 080916C (long GRB) Guiriec [FD] et al. 2015



Warning:
spectral analysis based
on forward folding technique

Weak quasi-thermal components in GRB spectra?

Non dissipative photosphere in magnetized outflows:

- Initial geometry is not specified
- Beyond R_{sph}, the flow is radial (opening angle θ)

- Total injected power in the flow: $\dot{E}$
  - -fraction ε_{th} is thermal
  - -fraction $1-\varepsilon_{th}$ is magnetic

- Acceleration is complete at $R_{sat} > R_{sph}$
- The final magnetization (above R_{sat}) is σ

- Photospheric emission occurs at R_{ph}
- Non-thermal emission occurs above R_{ph} with efficiency f_{NT}

Three main parameters: ε_{th}, σ, f_{NT}

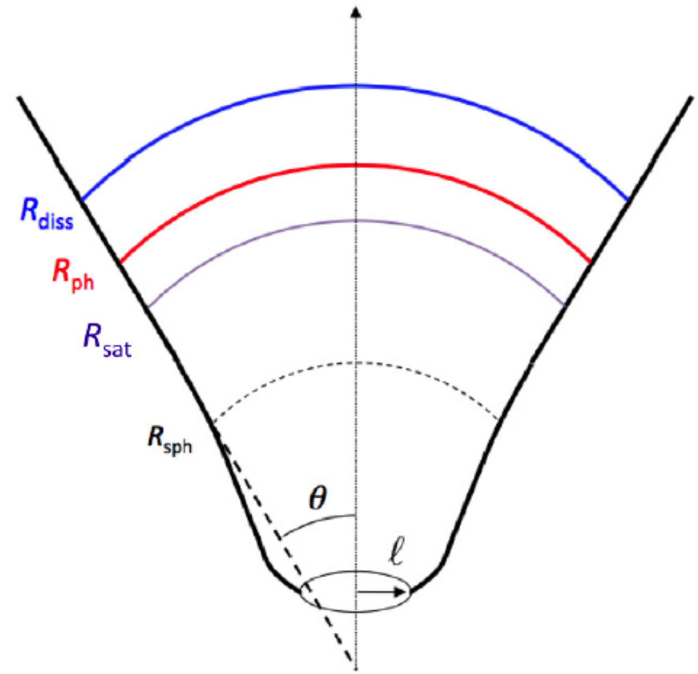


Fig. 1. Schematic view of the problem geometry. The flow emerges from the central engine through a "circular opening" of radius ℓ. Beyond a radius R_{sph} it expands radially within a cone of half opening θ. The acceleration is completed at R_{sat}. The photosphere is located at R_{ph} and dissipation of kinetic and/or magnetic energy takes place at R_{diss}.

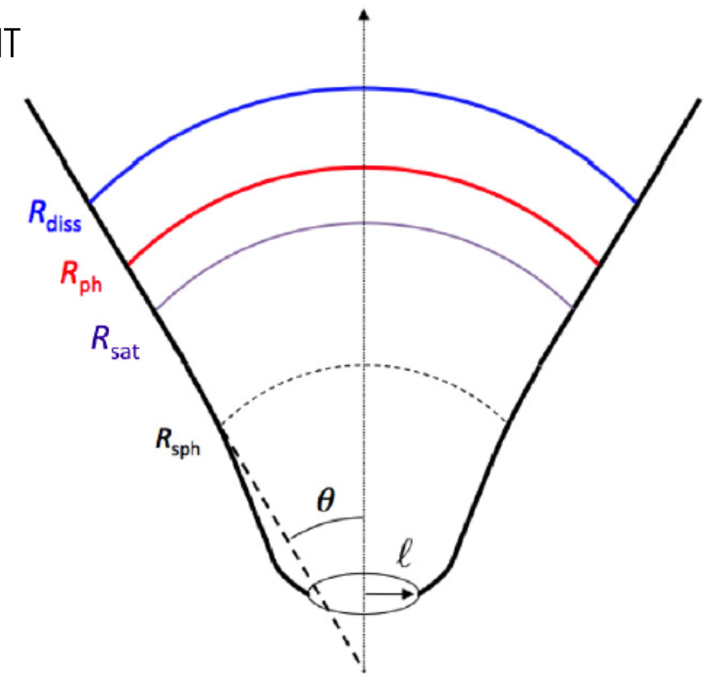
Hascoet, Daigne & Mochkovitch 2013

Weak quasi-thermal components in GRB spectra?

Three main parameters: ε_{th}, σ, f_{NT}

Inversion method described by Pe'er et al. 2007

R_0, R_{ph}, $\Gamma = F(\text{data} ; \varepsilon_{th}, \sigma, f_{NT} ; z)$



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Hascoet, Daigne & Mochkovitch 2013

Weak quasi-thermal components in GRB spectra?

Three main parameters: ε_{th}, σ, f_{NT}

Inversion method described by Pe'er et al. 2007

$$R_0 \simeq \left[\frac{D_L \mathcal{R}}{2(1+z)^2}\left(\frac{\phi}{1-\phi}\right)^{3/2}\right] \times \left[\frac{f_{NT}}{\epsilon_T}\right]^{3/2},$$

$$\Gamma \simeq \left[\frac{\sigma_T}{m_p c^3}\frac{(1+z)^2 D_L F_{BB}}{\phi}\frac{1-\phi}{\phi}\right]^{\frac{1}{4}} \times \left[(1+\sigma)\, f_{NT}\right]^{-1/4},$$

$$R_{ph} \simeq \left[\frac{\sigma_T}{16 m_p c^3}\frac{D_L^5 F_{BB} \mathcal{R}^3}{(1+z)^6}\frac{1-\phi}{\phi}\right]^{\frac{1}{4}} \times \left[(1+\sigma)\, f_{NT}\right]^{-1/4},$$

$$\phi = F_{BB}/F_{tot} \qquad \mathcal{R} = \left(\frac{F_{BB}}{\sigma T_{BB}^4}\right)^{1/2}.$$

R_0, R_{ph}, Γ = F(data ; ε_{th}, σ, f_{NT} ; z)

Different scenarios:

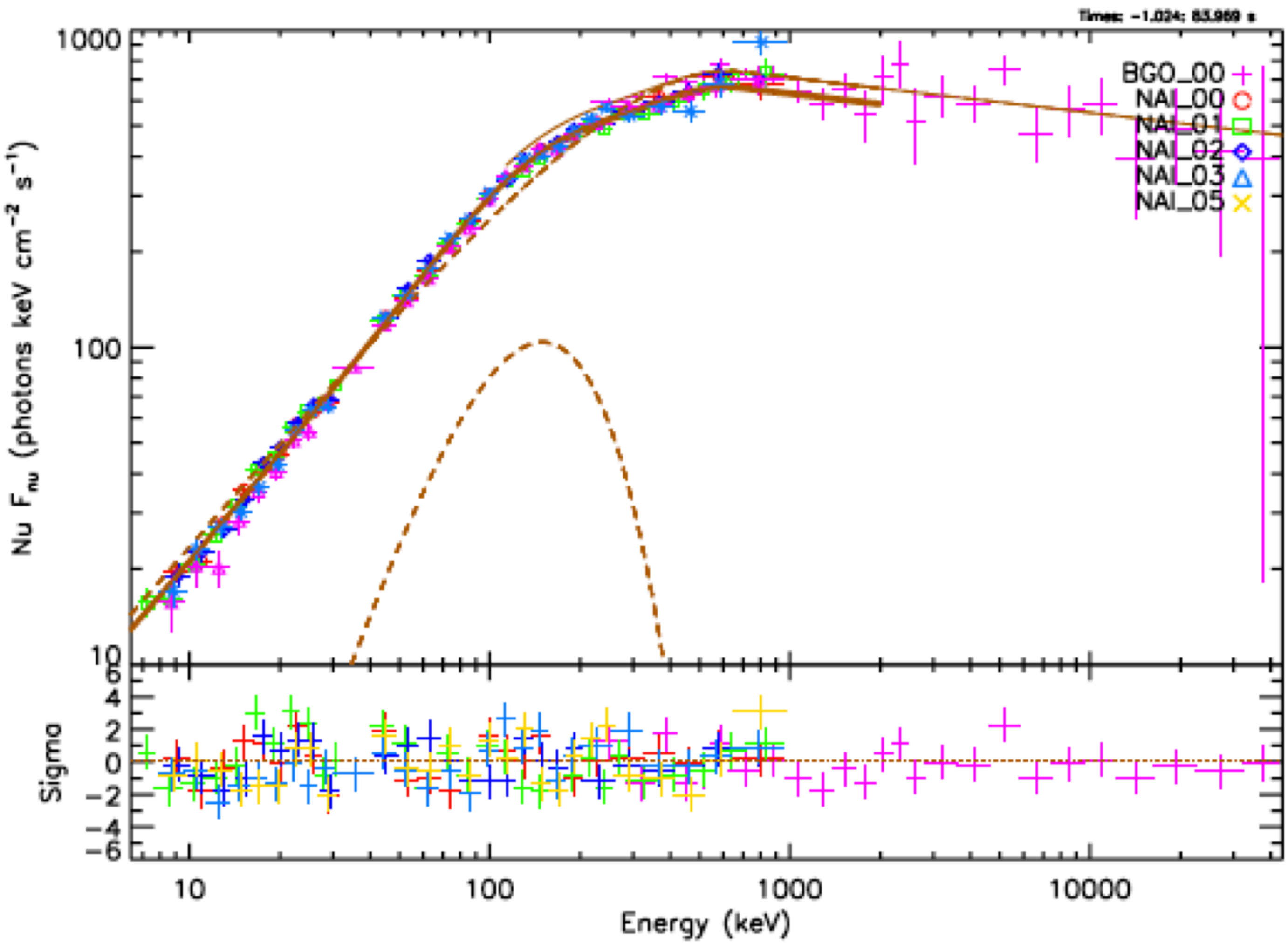
-Thermal acceleration (standard fireball): $\varepsilon_{th}=1$ & $\sigma=0$ and $f_{NT} < 10\%$ (internal shocks)

-Magnetized outflows: $\varepsilon_{th}<1$

- -efficient acceleration: σ < 0.1-1 and $f_{NT} < 10\%$ (internal shocks)
- -mag. outflow at large distance: σ > 1 and $f_{NT} > 30\%$ (reconnection)

Exemple: GRB 100724B

Thermal component is weak (4% of total)



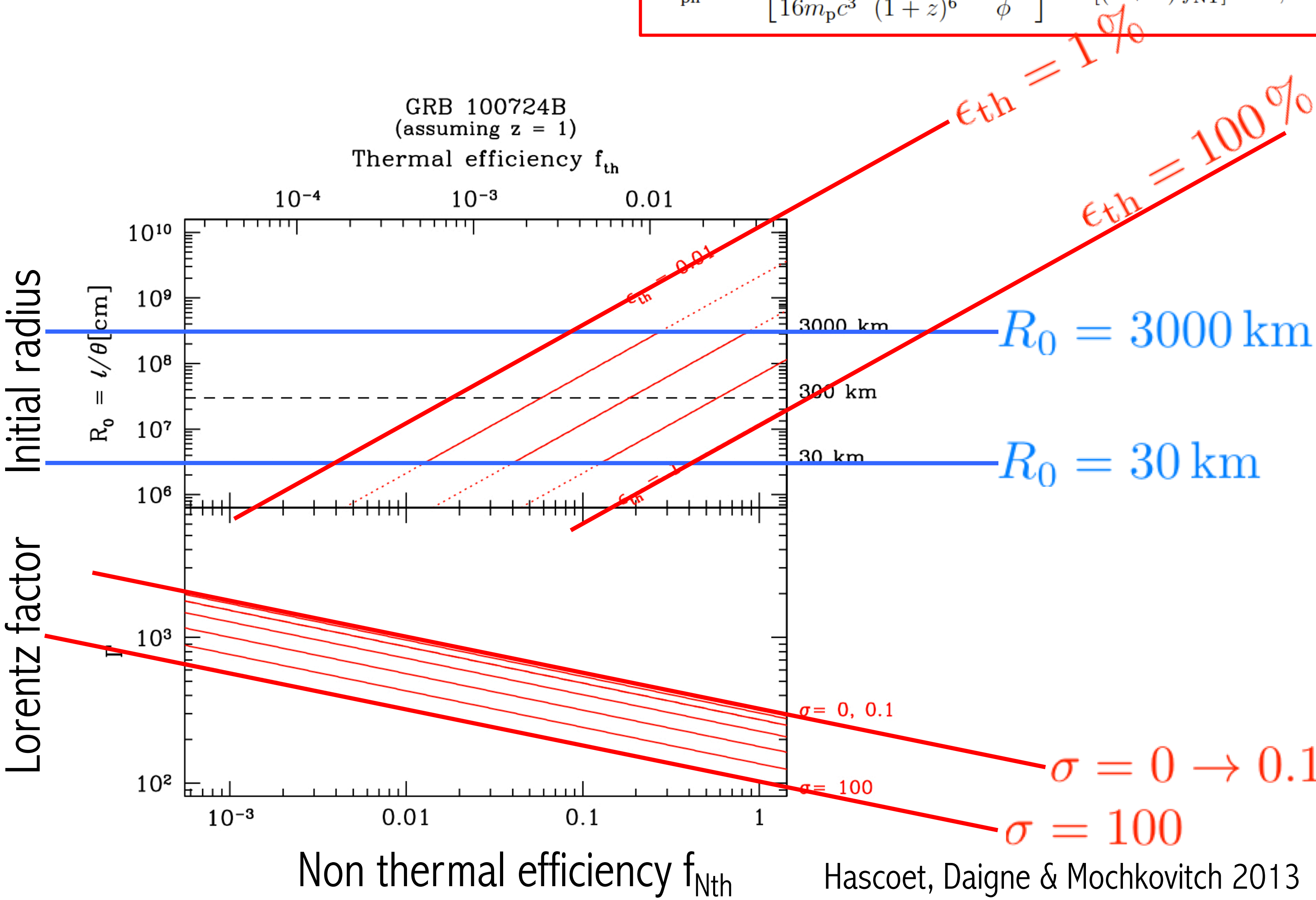
Guiriec [FD] et al. (2011)

Exemple: GRB 100724B

$$R_0 \simeq \left[\frac{D_L \mathcal{R}}{2(1+z)^2}\left(\frac{\phi}{1-\phi}\right)^{3/2}\right] \times \left[\frac{f_{NT}}{\epsilon_T}\right]^{3/2},$$

$$\Gamma \simeq \left[\frac{\sigma_T}{m_p c^3}\frac{(1+z)^2 D_L F_{BB}}{\phi}\frac{1-\phi}{\phi}\right]^{\frac{1}{4}} \times \left[(1+\sigma)\, f_{NT}\right]^{-1/4},$$

$$R_{ph} \simeq \left[\frac{\sigma_T}{16 m_p c^3}\frac{D_L^5 F_{BB} \mathcal{R}^3}{(1+z)^6}\frac{1-\phi}{\phi}\right]^{\frac{1}{4}} \times \left[(1+\sigma)\, f_{NT}\right]^{-1/4},$$

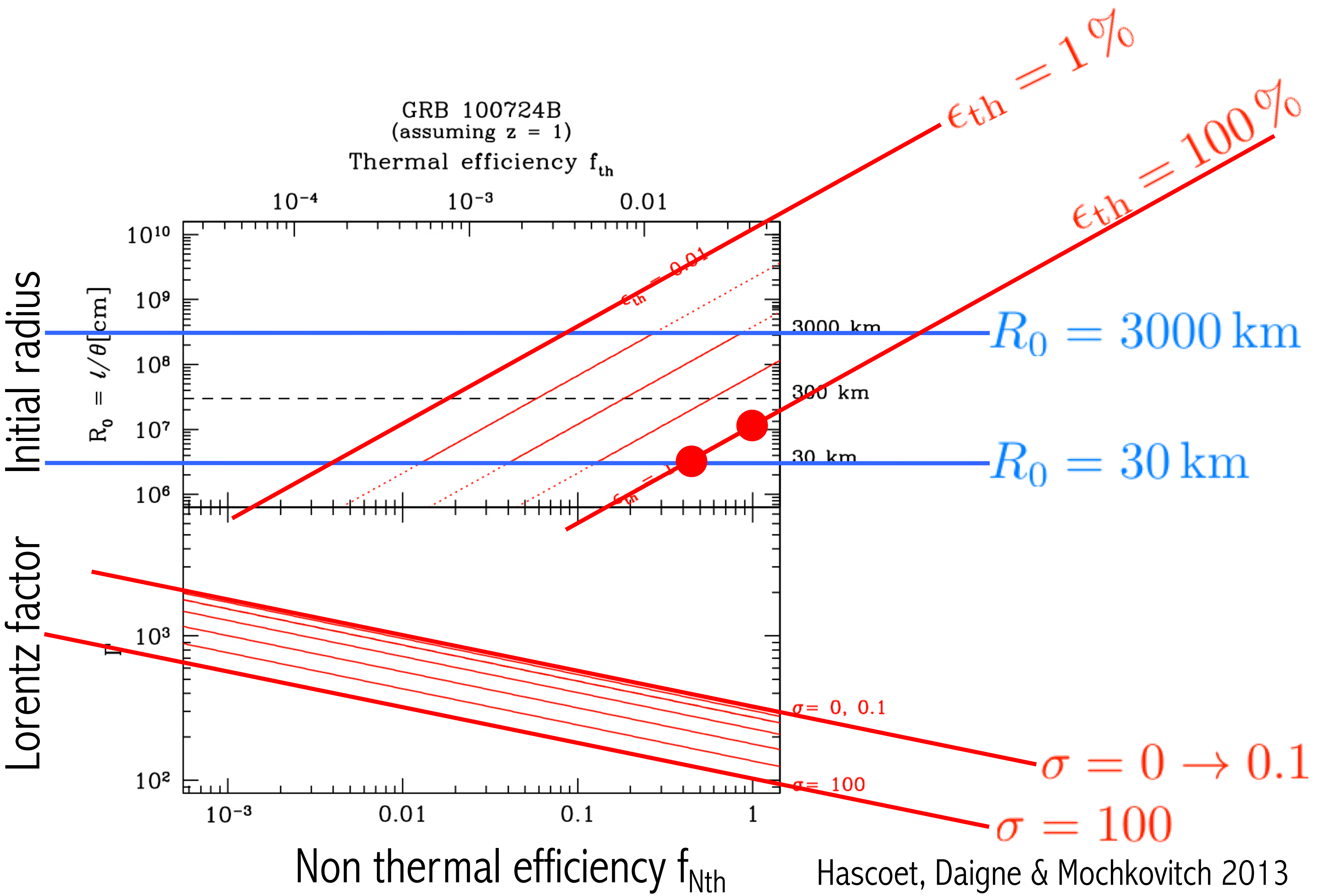


Observations taken from Guiriec et al. (2011)

Hascoet, Daigne & Mochkovitch 2013

Exemple: GRB 100724B

- Incompatible with the standard fireball, except for a very low R_0 + very high non-thermal efficiency



Observations taken from Guiriec et al. (2011)

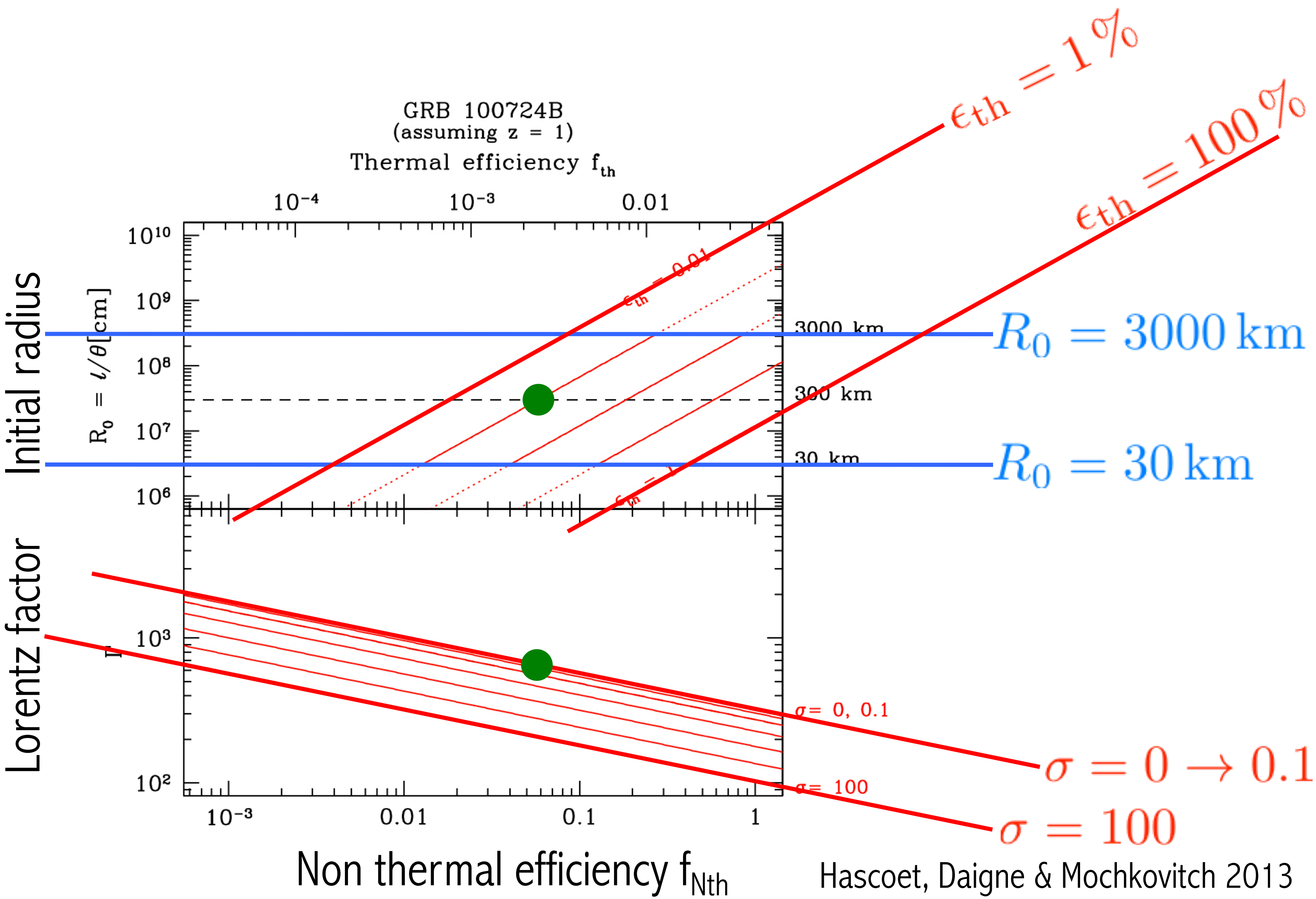
Hascoet, Daigne & Mochkovitch 2013

Exemple: GRB 100724B

ε_{th} must be small to have a low non-thermal efficiency compatible with internal shocks (here: f_{NTh}~6% and Γ~670)

$\epsilon_{\rm th} = 0.03$
$\sigma \ll 1$

● Efficient magnetic acceleration + internal shocks

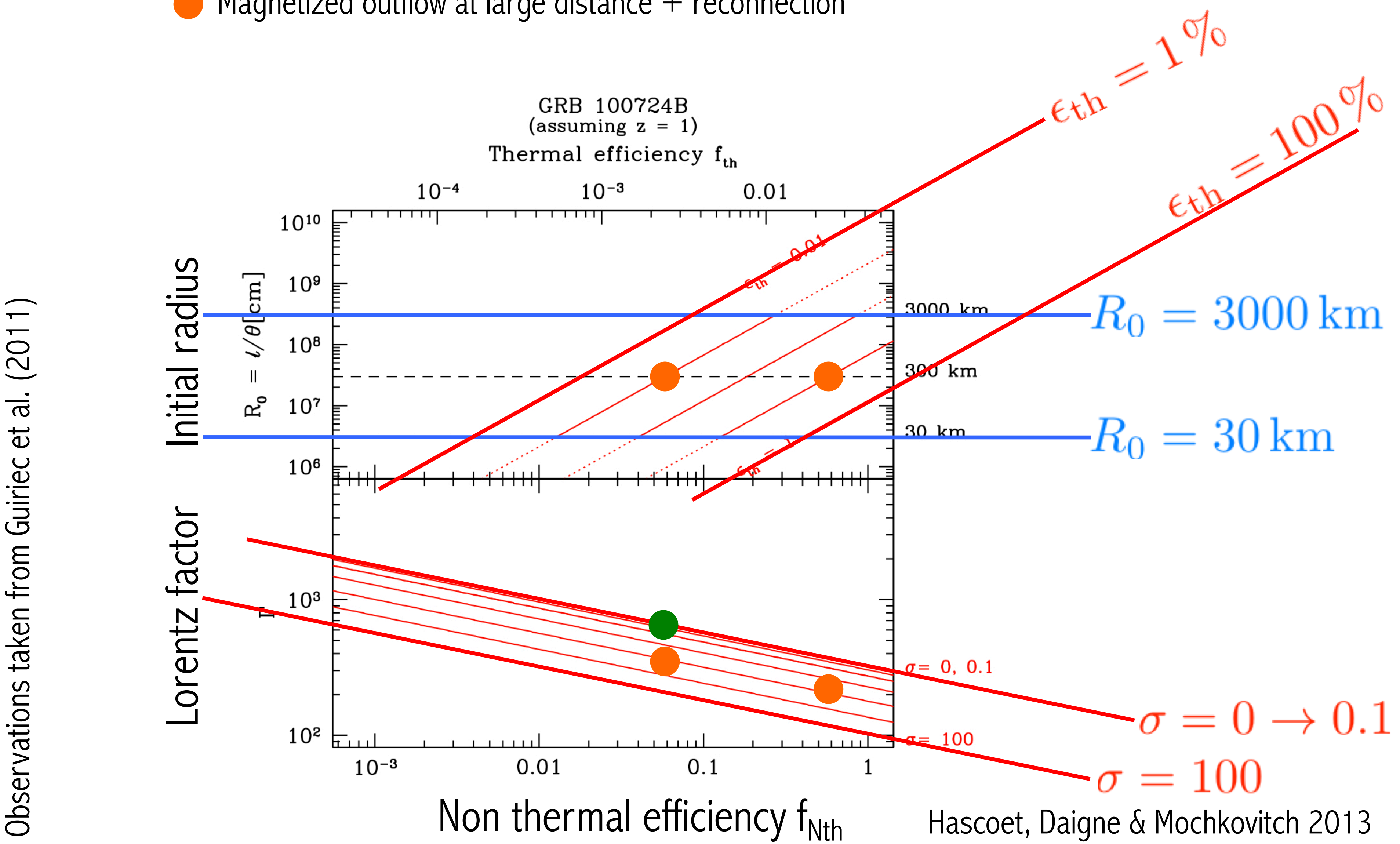


Observations taken from Guiriec et al. (2011)

Hascoet, Daigne & Mochkovitch 2013

Exemple: GRB 100724B

- Efficient magnetic acceleration + internal shocks
- Magnetized outflow at large distance + reconnection



Hascoet, Daigne & Mochkovitch 2013

Other exemples and summary

- Most GRBs have a weak photosphere and are not compatible with the standard fireball : $\varepsilon_{th} < 1\%$ (Daigne & Mochkovitch 2002)

- Exemples: GRB100724B (long)
  -non compatible with a standard fireball
  -compatible with
  efficient mag. acceleration + internal shocks ($\varepsilon_{th} < 1\text{-}10\%$)
  or magnetized outflow + reconnection (but low efficiency or $\varepsilon_{th} > 30\%$)
  (Guiriec et al. 2011; Hascoet et al. 2013)

  GRB120323A (short) : similar conclusions, but allowing a larger $\varepsilon_{th}>50\%$

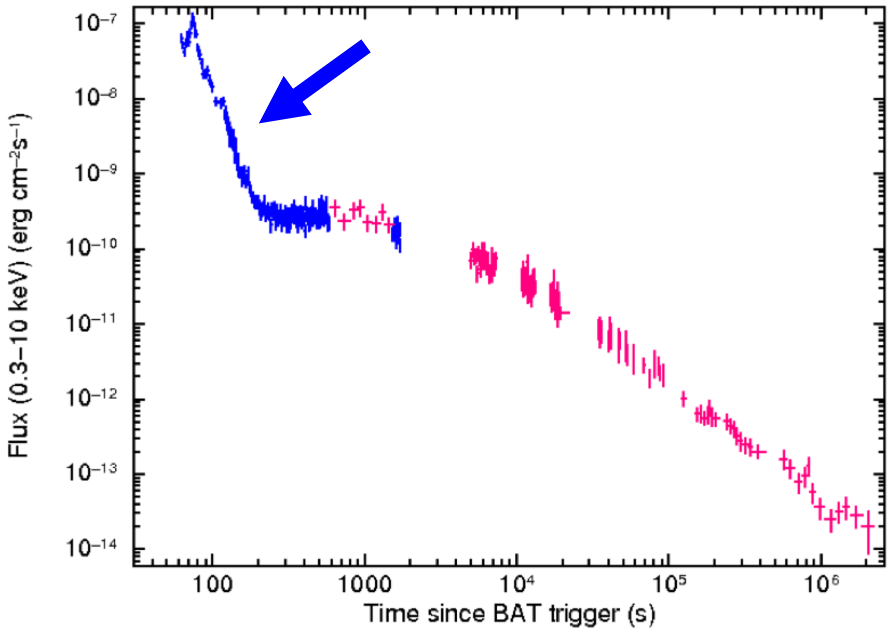
  GRB 090902B: only case compatible with standard fireball

- It implies a large initial magnetization in GRB outflows:
  What is the magnetization σ at large distance?
  Internal dissipation by shocks or reconnection?

- If shocks are present: low magnetization at large distance (efficient acceleration?)

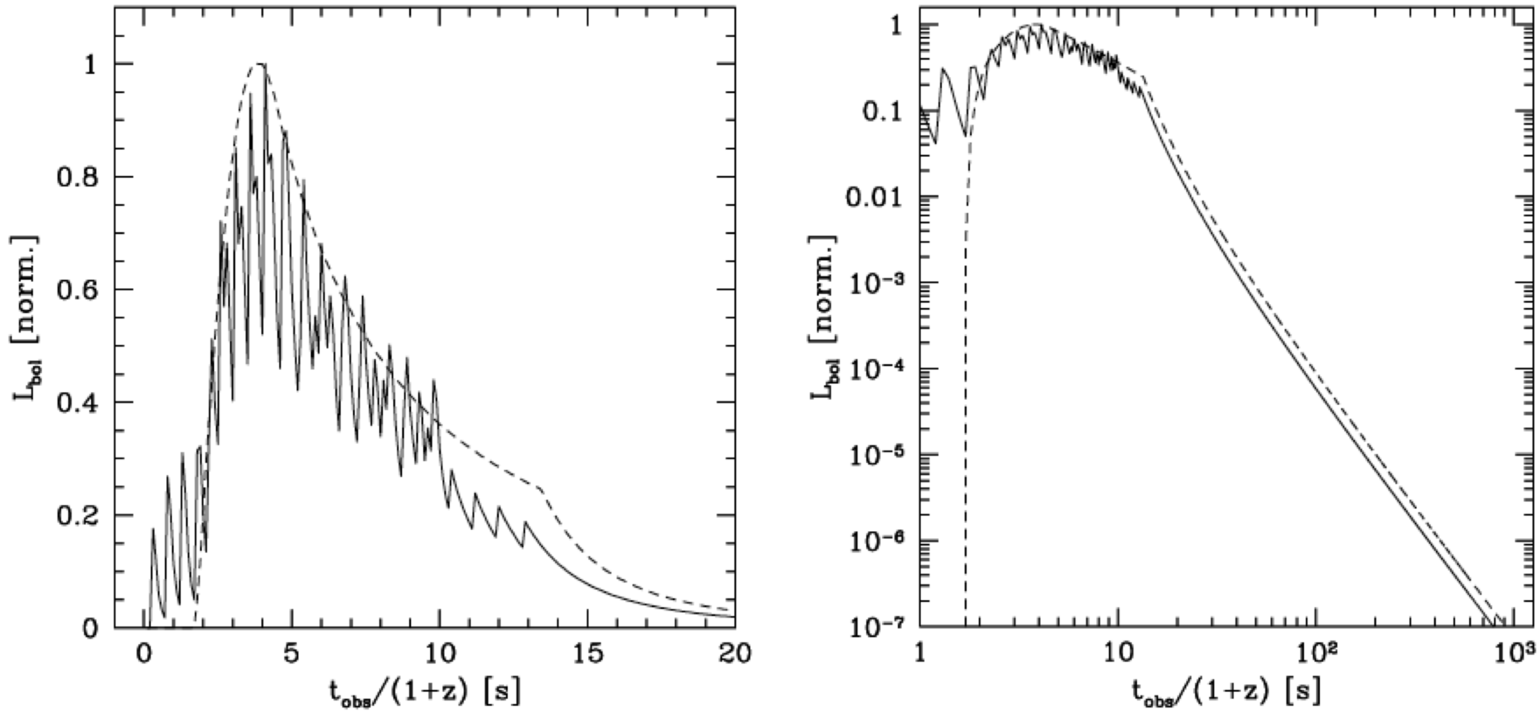
What is the radius of the prompt emission? Constraints from the X-ray early steep decay

Swift BAT+XRT



(Page et al. 2007)

High latitude emission at the end of the prompt phase



Final radius of the order of Γ^2 c t_{burst}

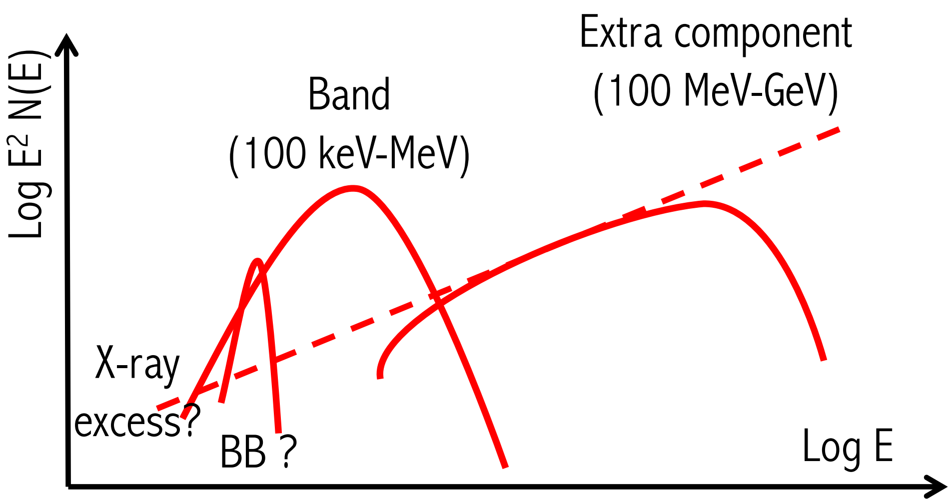
High-latitude emission interpretation of the early steep decay:
-Compatible with internal shocks or reconnection.
-Incompatible with photospheric models (decay: intrinsic source evolution).

Hascoët, Daigne & Mochkovitch (2012)

Spectrum

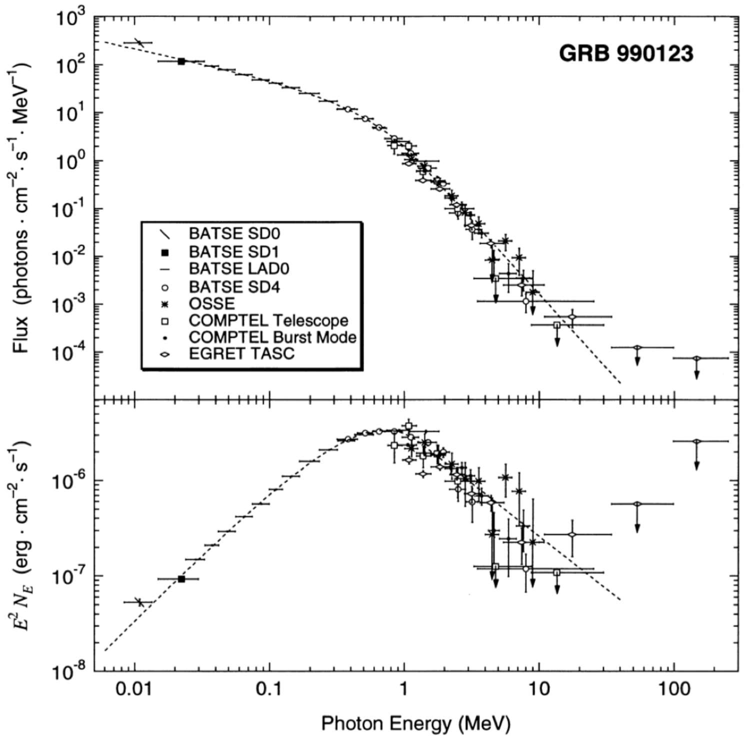
Spectrum: observational issues

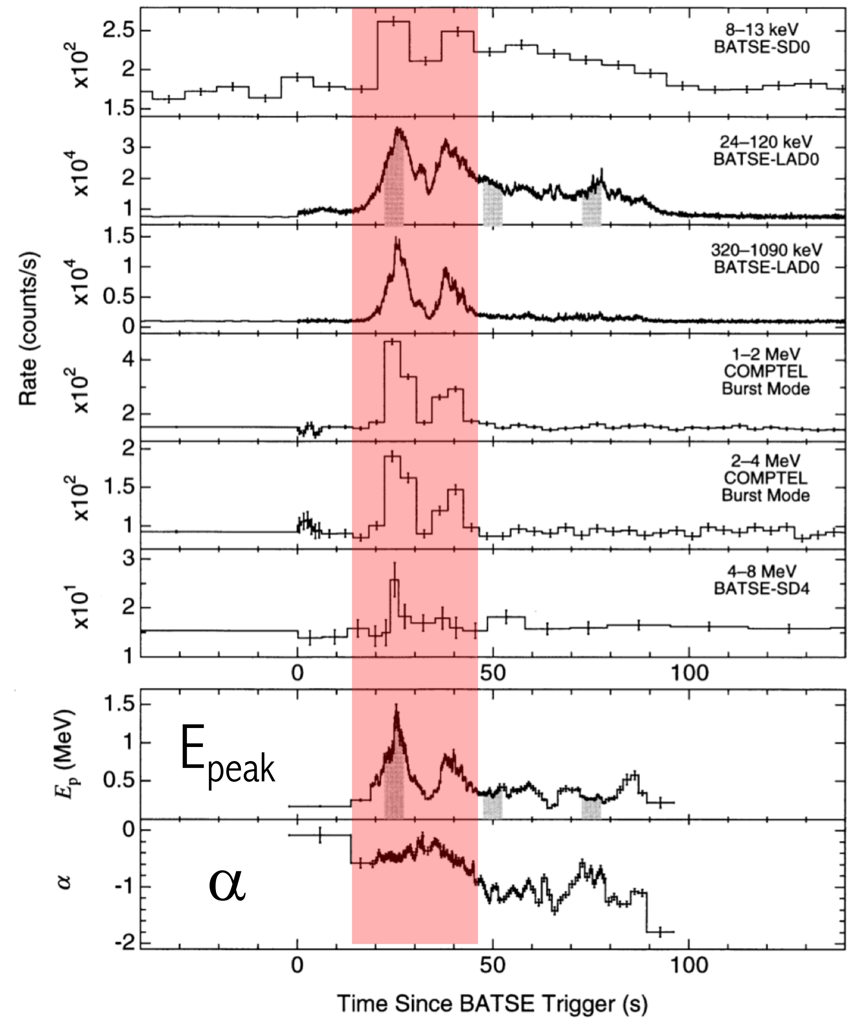
- Band vs Band+BB: different low-energy photon index?
  Compatible with (modified) fast cooling synchrotron?
  e.g. GRB120323A α=-0.92 $\rightarrow$ -1.4 Guiriec [FD] et al. 2013
  GRB 080916C α=-1.0 $\rightarrow$ -1.2 Guiriec [FD] et al. 2015
  etc.
- Inconsistency between time-integrated and time-resolved analysis?
- Shape of the extra-component in LAT is not well constrained.
  Is the X-ray excess real?



Spectrum: observational issues

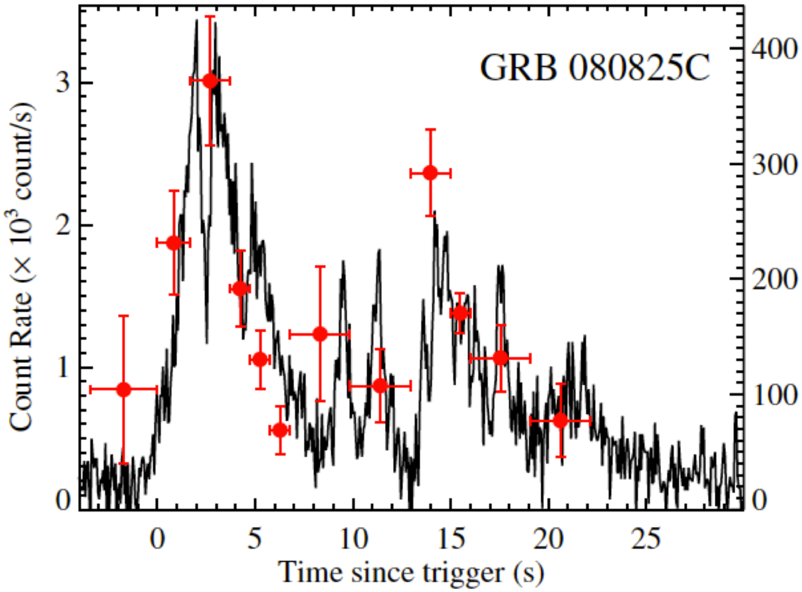
e.g.   GRB 990123 (Briggs et al. 2000)

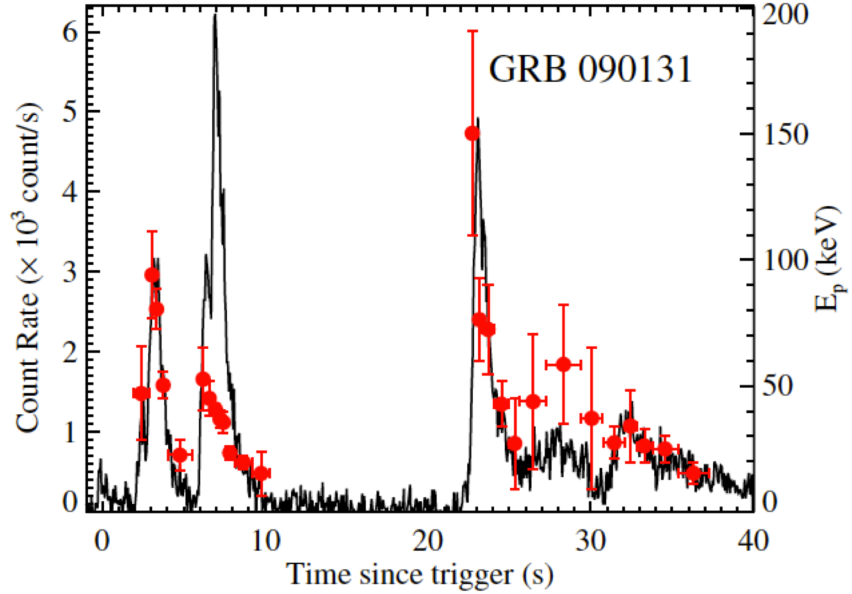


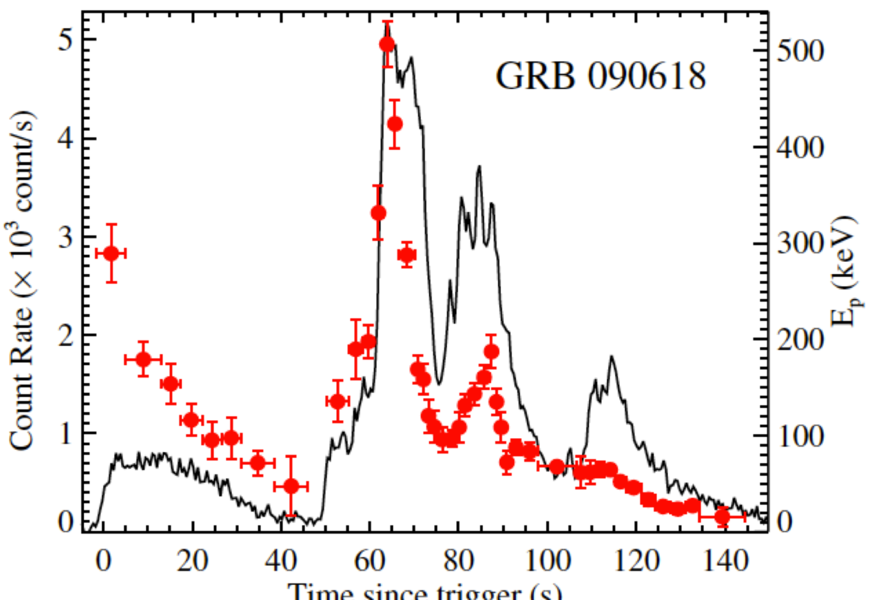


Band function used both in time-integrated/resolved analysis

Spectral evolution



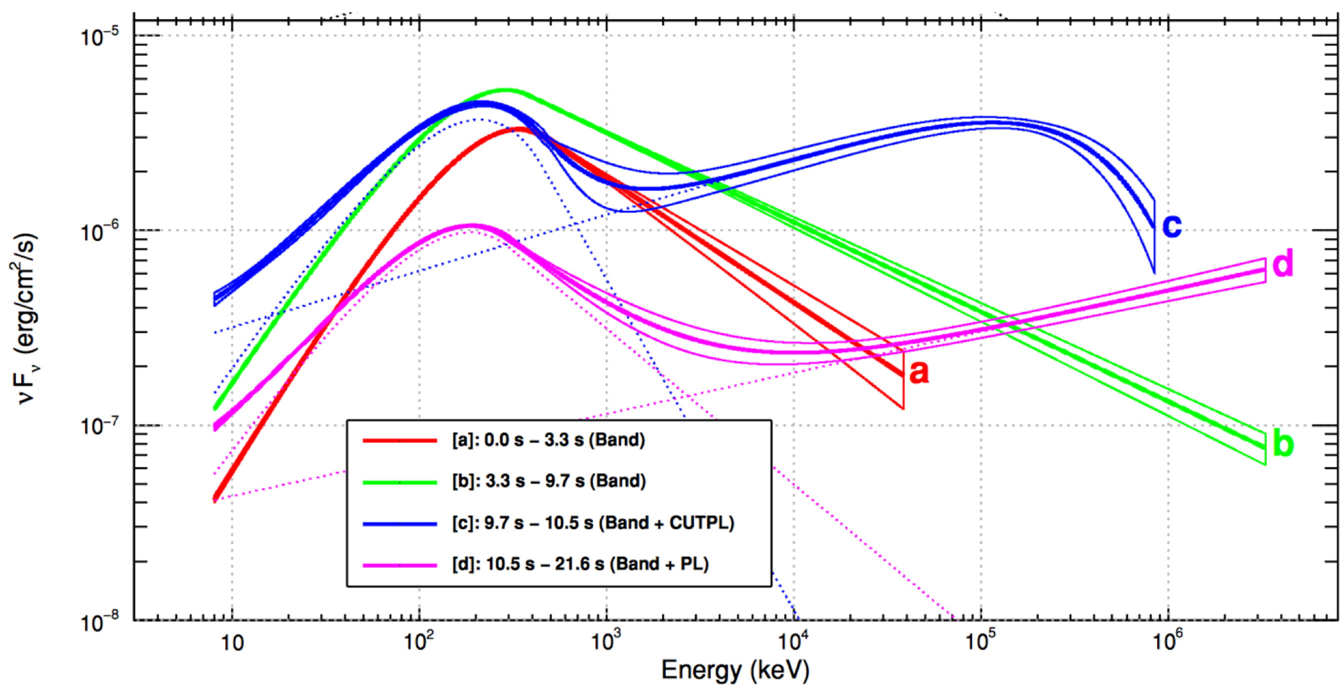




GBM bursts — Li et al. 2012

Spectrum: observational issues

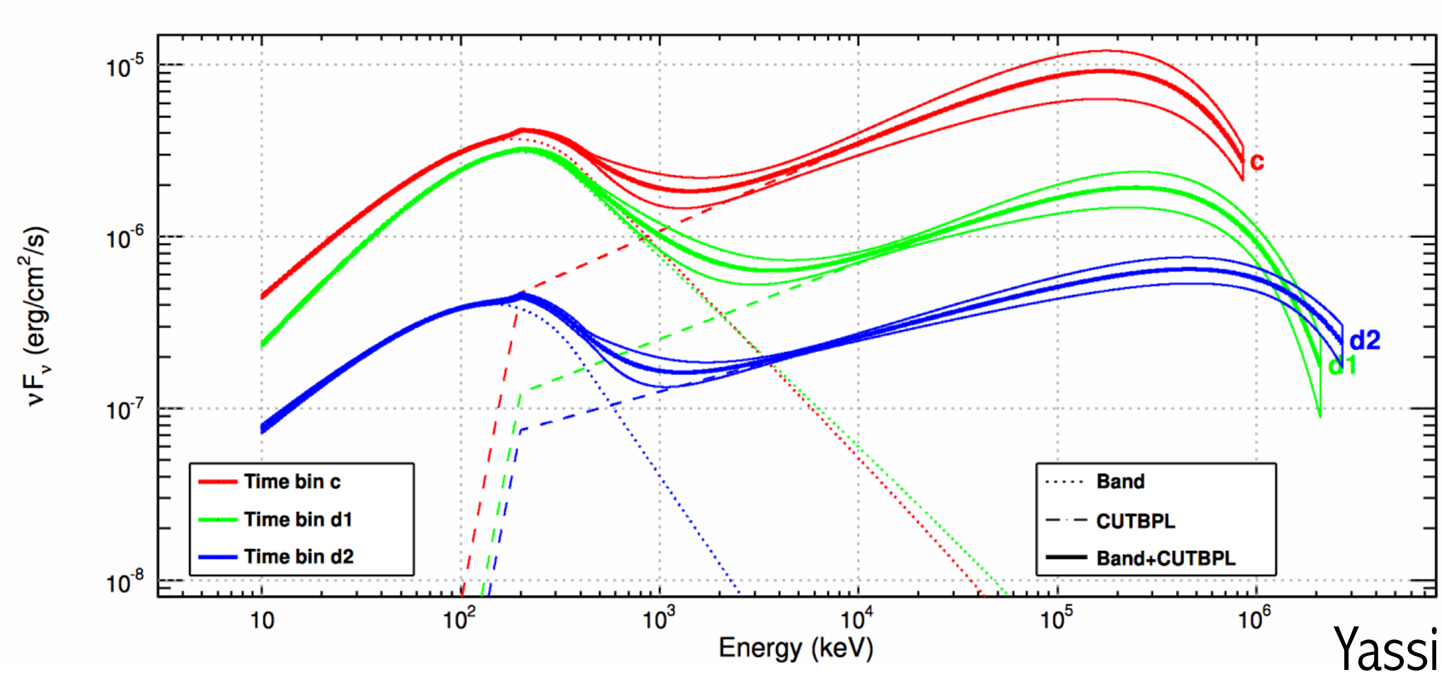
e.g. New analysis of GRB090926A with Pass 8 (LAT photons × 2.4)



Ackermann et al. 2011: Band (steep α) + PL (with cutoff in bin c) – X-ray excess

Spectrum: observational issues

e.g. New analysis of GRB090926A with Pass 8 (LAT photons × 2.4)



Yassine+17 [FD]

Band + broken PL + cutoff in bins c and d

-X-ray excess disappears

-Band ($\alpha \longrightarrow$ -1)